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The evaluation, which consists of two volumes of text and 15 trip reports, analyzes the experiences of the Europeans with waste to energy systems. The text is a compilation of the data obtained during visits to 15 major European refuse fired energy systems and visits to systems vendors, government agencies and other plants.

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Evaluation of Design Practices

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EUROPEAN REFUSE-FIRED ENERGY SYSTEMS

Evaluation of Design Practices

Volume 2

This report (SW-176C.2) describes work performed for the Office of Solid Waste under contract no. 68-01-4376 and is reproduced as received from the contractor. The findings should be attributed to the contractor and not to the Office of Solid Waste.

U.S. ENVIRONMENTAL PROTECTION AGENCY
1979

i.b

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An environment protection publication (SW-176C.2) in the solid waste management series.

DIGEST AND MAJOR CONCLUSIONS

The major conclusion is that the mass burning of unprepared municipal solid waste in heat recovery boilers is well established, and can be a technically reliable, environmentally acceptable and economic solution to the problem of disposal of solid wastes. It is not as cheap as use of currently available landfills. However, when the cost is considered of upgrading current landfills and established new landfills in accordance with the Resource Conservation and Recovery Act (RCRA) provisions, these mass burning waste-to-energy systems are expected to compare more economically with true sanitary landfills.

Another significant conclusion is that many European areas are moving steadily in the direction of Energy and Environmental Parks that often include refuse burning, animal rendering, electricity production, sewage disposal, industrial steam generation, hot water district heating, etc.

A surprising conclusion is that over a wide range of plant sizes from 200 to 1,600 tons per day there appears to be little significant economy of scale. The data suggests that the net operating and owning costs for plants within these size ranges and with the same plant configurations normalized for inflation, exchange rates, site costs and so forth fall in the range of $6 to $36 per ton with the average about $16. While this range appears significant, the factors that cause the variation are not size related as much as previously thought.

A major impetus for the development in European of waste-to-energy systems was the finding that it was possible to control air pollution from the burning of wastes by cooling the dirty exhaust gases. Concurrent with this influence was the disenchantment with old leaching landfills as a long-range solution to the solid waste problem in very crowded countries.

The cost of alternative energy forms (coal, oil, gas) will become even more important to the development of refuse-fired energy systems. Yet the total potential energy in the wastes of a modern community will be less than a tenth of its total energy demand. Hence, waste-to-energy alone cannot be expected to become a major energy source.

Many conditions in the U.S. have been different, hence waste-to-energy has not advanced as rapidly as in Europe. Some of these differences will continue, but we are moving rapidly to similar conditions in most of our metropolitan areas. Hence the lessons that have been larned in 80 years of refuse fired energy plant (RFEP) experience in Europe can be effectively utilized by many U.S. communities. We hope that this series of reports will be of help to community officials and technologists in applying those lessons to U.S. environmental and energy problems.

PREFACE

These documents are a two volume evaluation of European refuse - fired energy systems design practices, which is a condensation and analysis of trip reports describing visits in 1977 to fifteen (15) European refuse fired steam and hot water generators. Interspersed are comments about another fifteen (15) plants for which official trip reports were not prepared, i.e., a total of thirty (30) resource recovery plants were visited. In addition, visits to five (5) federal environmental protection agencies have provided additional insight to solid waste management trends, legislation and perspectives on resource recovery technologies.

The material in the reports describing the visits to the fifteen (15) plants has been reviewed by the European system vendors and their respective American licensees. The two volume evaluation report has also been reviewed, but the comments of the various reviewers has not been incorporated in the text. Rather, their comments are presented in toto in the appendix to Volume II.

Battelle Columbus Laboratories maintains ultimate responsibility for report content. The opinions set forth in this report are those of the Battelle staff members and are not to be considered EPA policy. There may be some minor errors and certainly differences of opinion in the report, but these do not take away from the usefullness of the document.

The intent of the report is to provide decision making information. The reader is thus cautioned against believing that there is enough information to design a system. Some proprietary information has been deleted at the request of vendors. While the contents are detailed, they represent only the tip of the iceberg of knowledge necessary to develop a reliable, economical and environmentally beneficial system.

The selection of particular plants to visit was made by Battelle, the American licensees, the European grate manufacturers, and EPA. Purposely, the sampling is skewed to the "better" plants that are models of what the parties would like to develop in America. Some plants were selected because many features evolved at the plant. Others were chosen because of strong American interest in co-disposal of refuse and sewage sludge.

The two volumes plus the trip reports for the 15 European plants are available through the National Technical Information Source, Springfield, Virginia, 22161. Of the 17 volumes, only the Executive Summary has been prepared for wide distribution.

ACKNOWLEDGEMENTS

The project owes much of its success to the many European vendors, plant personnel, city officials, and European environmental protection agency staff who opened up so fully to the visiting Battelle team. It is an established fact that Europe is far advanced over America in commercialization of the refuse-fired, steam- and hot-water generation technology. This fact and the accompanying pride of accomplishment are likely causes for the excellent cooperation we received and outpouring of valuable information from visited European professionals. Frankly, the amount of information freely provided has amazed and challenged these researchers. The authors hope that we have been able to summarize accurately the data provided.

Our appreciation is also extended to the EPA staff of David Sussman--Project Officer, Steve Levy--Program Manager, and to Steve Lingle--Chief of Technology and Markets Branch.

The detailed listing of the many names, organizations and addresses is to be found in Part II. Each person and organization should realize that they have contributed to the advancement of solid waste management in America.

ORGANIZATION OF REPORT

The report consists of twenty three chapters in two volumes. Chapter A, The Executive Summary and Chapter B, The Inventory of Waste to Energy Systems are being published by the Office of Solid Waste for wide distribution. The Executive Summary and Inventory are also included in the two volume set, which is available through NTIS.

Volume I contains information relating to the implementation of the systems, whereas Volume II contains technical information about the units themselves. The paragraphs in the Executive Summary follow the same format.

INTRODUCTION

Background

Since 1896 (in Hamburg, West Germany), communities have been converting municipal refuse into electricity and other energy uses. Many of the early systems were batch operated with manual refuse feeding and manual ash removal.

Between the two world wars, many developments were made in refuse handling in general and grate systems in particular. There were also major improvements in the refractory wall furnaces and the separate waste heat boilers.

Many of the systems were destroyed during World War II. The evolution of the water-tube wall integrated furnace/boiler began in the 1950's. It paralleled developments 30 years earlier in the water tube walled pulverized, coal-fired boiler/furnace.

More precisely, the world's first integrated water-tube wall furnace/boiler began operation at Berne, Switzerland in 1954. Two 100 tonne per day units produced steam to make electricity. Some steam was sent to industry. Other steam was sent to a steam-to-hot-water heat exchanger. This hot water was then sent to the local district heating network. This original Von Roll plant continues to operate 25 years later in 1979.

The business of designing and building those and other wate-to-energy systems has grown exponentially since 1954. Now we can point to at least 522 places in the world where energy conservation objectives are met by recovering values.

Objective

The general objective of the project was to gather information about European waste-to-energy practice and to interpret this experience as it may be commercially practicable in the U.S. The subobjectives are listed as follows:

1. Report on actual technical, economic, environmental, and social experience in application of the European technologies of (1) integrated water tube wall furnace/boiler and (2) refractory wall furnace/waste heat boiler.
2. Aid American decision makers and engineers in utilization of the successful experience of their European counterparts.
3. Describe in a technical manner how successful operations are achieved and how unsuccessful operations are avoided.
4. Prepare Report -- "Evaluation of European Refuse-Fired Energy Systems Design Practices".
5. Prepare 15 Trip Reports describing systems visited.

Scope

The geographic scope as clearly indicated in the title is Europe. However, there will be frequent references to systems in America and comments about other countries. For example, Japan has the greatest number of refuse-fired energy generating units (43) of any country in the world; with an installed capacity of 27,000 tons per day.

Several solid waste management topics are discussed. Some are beyond the original contract scope but are presented to give the reader a better perspective of the total picture. The refuse to energy systems are as follows:

- Water-tube wall furnace/integrated boiler
- Refractory wall furnace/waste heat boiler
- Vertical shaft pyrolysis

Other types include:

- Refuse transfer stations
- Hazardous waste transfer stations
- Landfilling
- Composting
- Rendering
- Pathological incineration
- Waste water treatment
- Environmental, Energy and Industrial Parks.

The chronological scope begins in 1876 when the first refuse to electricity system was built in Hamburg, West Germany.

The scope of processing capacity described ranges from the 120 tonne (132 ton) per day single line facility at Werdenberg-Liechtenstein to the large 1,630 tonne (1,793 ton) per day four line system at Paris: Issy-les-Moulineaux. The energy uses scope includes use of hot air, hot water, superheated water, steam, superheated steam and electricity.

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REFUSE HANDLING

Weighing of Refuse Received-General Comment

The amount of refuse handled is a major plant descriptor. Hence considerable attention is usually given to measuring the amount of waste received. Many of the plants visited used automatic recording of loaded truck weight as it arrived at the plant. Many truck driver's especially in Scandinavia, carried a coded identification card to be inserted into the card slot at the scale at the time of weighing. Previously established truck tare weights are recorded in the data processing equipment. The net weight delivered was immediately displayed in the weigh-master's booth, printed on the plant daily record and added to the monthly invoice which is sent to each of the private haulers or surrounding communities.

Many of the plants have experienced early difficulty with failure of the electronic system at the scales. In most cases these initial problems have been cleared up by the scale manufacturer. However, the electrical system usually requires frequent maintenance. A few large plants use 2 scales for redundancy and to handle peak loads without causing long lines of waiting trucks. One plant uses a separate scale to weigh the residue from the furnaces. Most scales are recalibrated once every year or two.

At very small plants the scale operation is observed and controlled by the crane operator who sits at plant control board. In such instances the main control room is located in such a way that the busy operator can view the trucks discharging to the pit. In some cases he also observes furnace condition by means of closed-circuit television.

In the larger plants the weighing operation is controlled by 1 or 2 scale operators who also direct the truck traffic through amplified voice instructions and sometimes by means of red and green signal lights.

At most plants it is the duty of the scale operator to detect bulky items and to instruct the driver to deposit them in a separate collection place.

Details on Specific Weighing Systems

Werdenberg, Switzerland

At Werdenberg, community and industrial wastes are delivered 5 days per week by eight regular trucks plus a few private ones. Incoming trucks are weighed on an 80-ton semi-automatic weigh scale which is operated by a plant worker who devotes about 1/4 time to weighing. The scale operator controls receipts from the rear of the control room which is on the second floor of the building. The weights, total and tare, are printed by an electro-mechanical recorder with digital readout. The scale is inspected, calibrated and serviced once per year. It is expected to last more than 20 years.

Baden-Brugg

Both public and private trucks deliver refuse to the Baden-Brugg plant 5 days per week. They are weighed on a Toledo scale which prints total, tare and net weights on a card. The scale is inspected the waste oil totaled 172 tons for the year.

Duesseldorf

Six to 7,000 tonnes of refuse is delivered ot the pit per week by 700 to 800 public and private trucks between 7:00 a.m. to 2:00 p.m., 5 days per week. On a 7-day week basis, hospital and hotes wastes are received.

Figure P-1 shows the plant property which is located in a concentrated industrial area well inside the city. The weigh scale is to the right of the figure. Two scales are provided--one on each side of the scale building--so that two trucks can be weighed simultaneously. The scales were built by Scheuck of Darmstadt. Normally there is one scale operator. At peak times, there are two. Peak times are from 8:30 a.m. to 10:30 a.m., 12:00 p.m., and 2:30 p.m. to 3:00 p.m.

The scale reading and tare are punched automatically on data cards. Also, an automatic typewriter logs the readings.

The scale service has been good with little maintenance. Calibrations are made every 3 years. The scale data-recorder has caused much difficulty. The electrical system requires repair 10 times per year.

When the scale operator observes bulky waste in a truck, he directs it to either the shredder or the shear.

Wuppertal

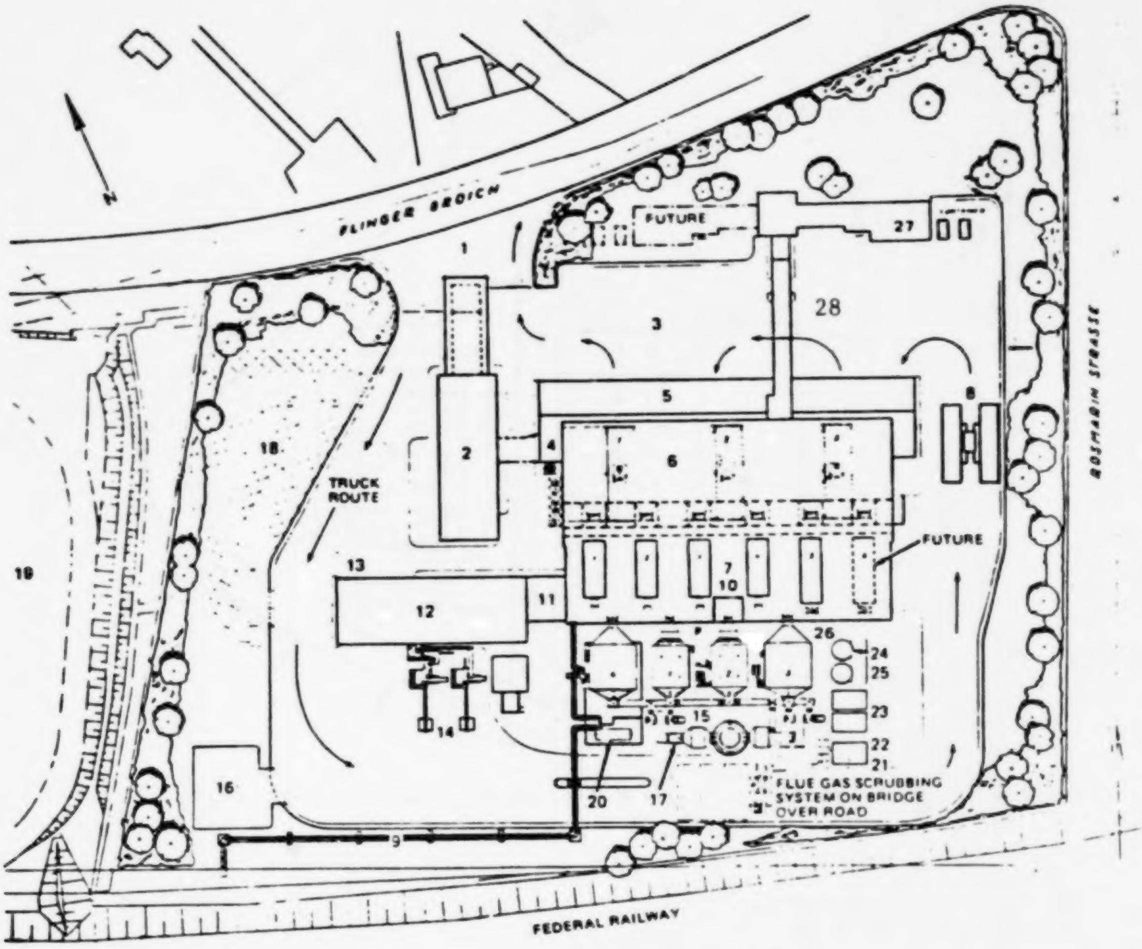
This new plant is not yet up to full capacity. Incoming trucks are weighed on 1 of 2 scales. Figure P-2 shows the plant arrangement. It is located on a steep hillside and the roadways are nearly all on a grade, hence the need for an entrance ramp close to the north wall of the tipping floor and a turning apron for a 180 degree turn to enter the tipping floor. The scales were reliable for the first 3 months of plant operation. Then the electronic sysstem malfunctioned. It was still causing some difficulty at the time of the visit, May 1977, 16 months after partial operation began.

Paris: Issy-les-Moulineaux

The weighing station at Issy is located centrally on the edge of the tipping floor as shown in the 2 views in Figure P-3. That elevated location is only 6.5 m (21.3 ft) above the nearby River Seine. The single mechanical scale has good accuracy and is officially calibrated annually by the government. It has posed no unusual maintenance problems.

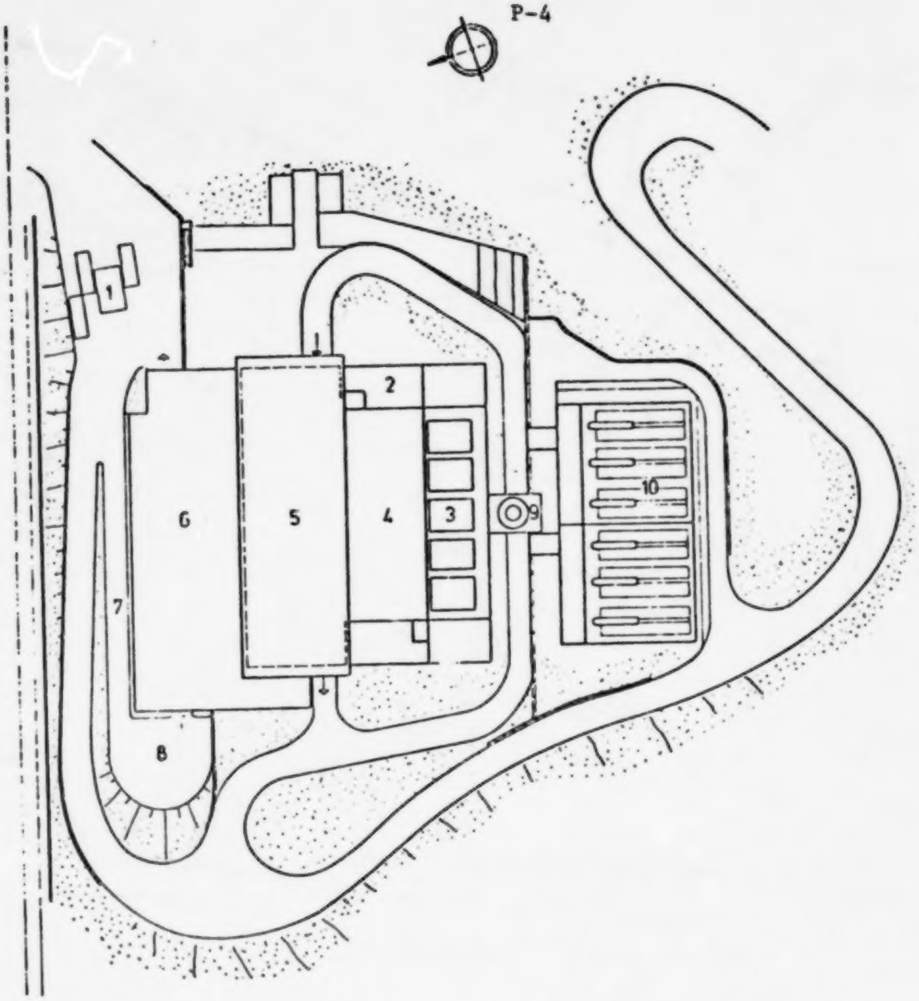
Zurich

At the Hagenholz plant there is one scale which has performed very well. It is calibrated once a year. Two men are asigned to the scale room. One of when monitors driver cleanup of any spillage on the tipping floor. Originally the refuse weight actually charged to the furnace hoppers was also measured by means of a load cell on the cranes. But when that device failed it was not repaired because the management feels that the energy produced is the best measure of plant performance, not how much refuse is processed.


N
FLINGER BROICH
1
FUTURE
27
28
3
5
8
ROSMARIN STRASSE
2
4
6
18
TRUCK ROUTE
19
13
12
11
7
10
FUTURE
26
24
25
23
15
22
21
14
20
17
16
9
FLUE GAS SCRUBBING SYSTEM ON BRIDGE OVER ROAD
FEDERAL RAILWAY

1. Entrance and Exit
2. Administration Building, Work Shop, Offices
3. Vehicle Turning Area
4. Bulky Waste Shear
5. Tipping Area
6. Refuse Storage Bunker with Charge Cranes and Feed Hoppers
7. Boiler House, Boilers # 1–6
8. Weight Scales
9. Steam and Condensate Lines Connecting to Flingern Power Plant
10. Control Room
11. Information Center
12. Ash Processing Building
13. Loading Hoppers for Processed Ash
14. Scrap Baling Presses
15. Exhaust Fans and Stack
16. Excess Ash Storage Bunker
17. RG Type Silencers
18. Parking Lot
19. Sportsfield – Area for Future Plant Expansion
20. Fuel Oil Tank
21. Circulation Pumps
22. Feed Tank
23. Settling Tanks
24. Lime Storage Silos
25. Neutralization Tank
26. Electrostatic Precipitators
27. Bulky Waste Shredder
28. Overhead Conveyor

FIGURE P-1. LAYOUT OF FLINGERN REFUSE POWER PLANT AT DUESSELDORF



1. Weigh station
2. Conference room
3. Machine shop and electrostatic precipitator
4. Boiler room
5. Refuse bunker
6. Tipping floor and bulky waste shear
7. Entrance ramp
8. Turning apron
9. Chimney
10. Air-cooled condenser

FIGURE P-2. MAP OF WUPPERTAL PLANT

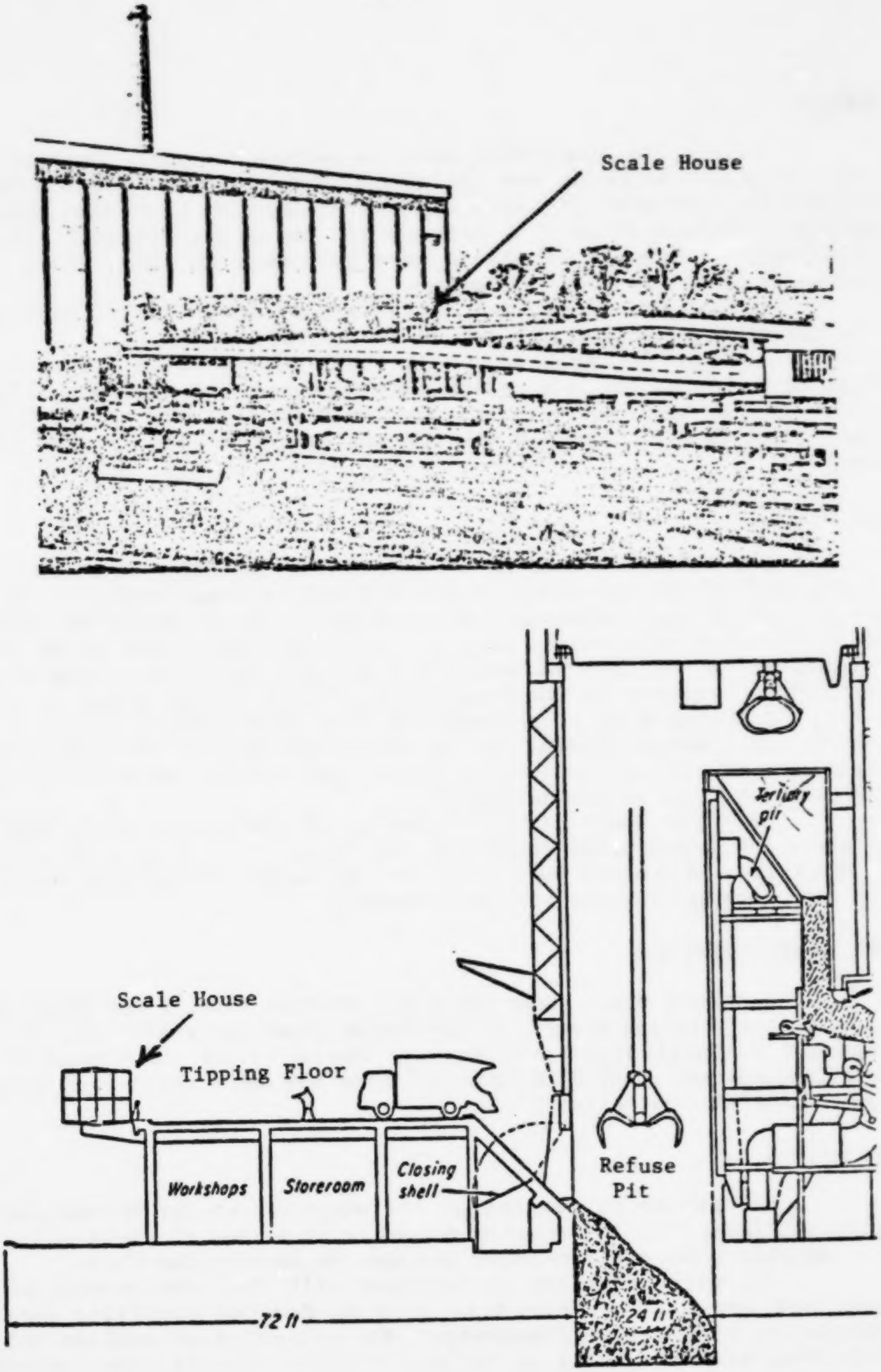

Scale House
Scale House
Tipping Floor
Workshops
Storeroom
Closing shell
Refuse Pit
Tertiary air
72 ft
24 ft

FIGURE P-3. TWO PARTIAL VIEWS OF THE RECEIVING AREA AT THE ISSY PLANT SHOWING THE SCALE HOUSE AT THE UNLOADING PLATFORM.

Hamburg

At the Stellinger-Moor plant in Hamburg the scale house is located near the plant entrance and the administration building. The plant originally purchased an inexpensive under capacity scale that caused much trouble. A mechanical level is used and the ensuing electrical resistance is measured. Many improvements have been made to this semi-automatic Essmann Scale manufactured in Hamburg.

Today, the weight indication almost never fails. However, the electric printer is available only 60 percent of the time.

Several notable attitudes have developed in response to the weighing problems. The local plant operations have about given up the truck scale and, instead, depend on the more reliable load cell on the crane. The truck scale is still used for weighing the burned residue removed from the plant.

The Hague

The weigh station is not operated by The Hague plant. Instead, it is operated by the municipal waste collection department. In 1976, the weigh station was relocated and modernized. It is situated between two scales, one for city trucks, one for private vehicles. The scale operator regulates traffic flow by means of a manually controlled red-green signal light on the approach to the scale house. Private trucks weigh in and then out. City trucks weigh in by insertion of a coded magnetic card into a slot at the scale which identifies the truck and causes immediate machine recording of the loaded weight, known tare weight. Automatic subtraction calculates the net weight delivered.

When the scale operator observes non-combustible bulky waste, such as steel appliances being delivered, he directs the driver to unload the objects in a walled-in yard near the new waste processing facility for later processing, reclamation and disposal.

Dieppe and Deauville

A single scale near the plant entrance enables the scale operator to weigh all entering trucks. At the Dieppe plant the scale room is in the separate administration building. At Deauville the scale house is at the site entrance and about 60 m (200 ft) from the main plant building which also houses administration.

Gothenberg

All refuse is weighed at the entrance to the Savenas plant area shown in Figure P-4. The weighing procedure is automated whenever possible. Most suppliers use customer cards and need no service therefore.

The weighing plant is equipped with four electronic weighing machines and a data recording system. Besides supplying continuous information to operational management, the system also enables automatic debiting and invoicing to be carried out. In addition, statistical information is received. Traffic inside the area and the emptying bay is

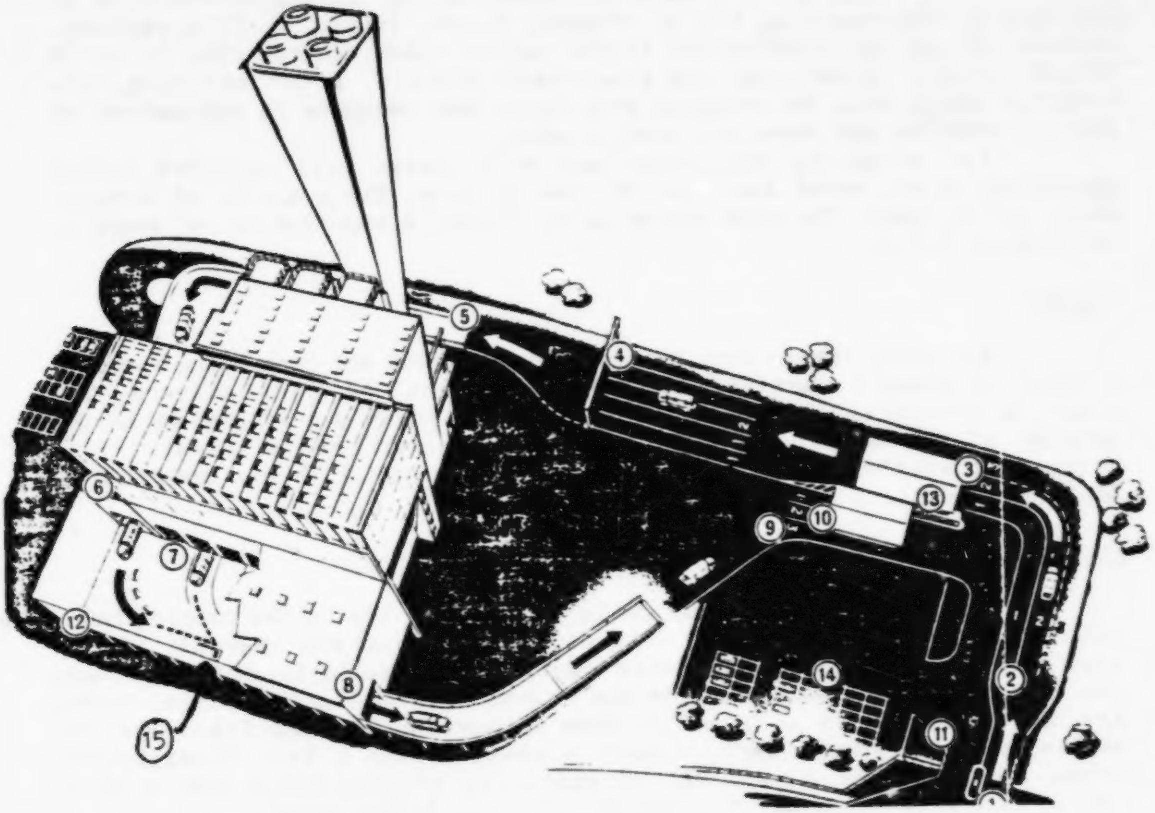


FIGURE P-4. TOP VIEW OF SAVENAS WASTE-TO-ENERGY PLANT SHOWING TRAFFIC PATTERN, WEIGH STATIONS AND DISTINCTIVE SQUARE 4-FLUE CHIMNEY. ONLY THREE FLUES IN USE. CHIMENY EQUIPPED WITH TWO-PASSENGER ELEVATOR AT GOTHENBURG (Courtesy GRAAB)

1. Entrance gate - monitored by television.
2. Classification lanes for large and small trucks.
3. Weigh station.
4. Traffic control area.
5. Entrance ramp.
6. Entrance to enclosed tipping hall.
7. Bunker doors.
8. Exit door.
9. Exit lanes.
10. Exit weight station.
11. Automatic exit gate.
12. Cafeteria (open 9 am to 2 pm).
13. Washroom
14. Parking
15. Traffic control room

monitored by a traffic controller stationed in the ceiling control room at the rear of the emptying bay or tipping floor. In low traffic periods, monitoring can be transferred to the central plant control room by use of closed circuit television and electronic signals. After emptying, the vehicles again pass the weighing room where tare weighing is carried out on certain vehicles and where any cash is paid.

The weighing equipment and data system have required little servicing, an estimated down-time of once per year. The scale is of Swedish make, by Stathmos. The data system is by General Automation Co. of Anaheim, California, U.S.A.

Uppsala

Arriving trucks are weighed, their weight and tare being recorded by means of plastic identification cards issued to the truck dirvers. The scale is sensitive to 20 Kg (44 lb). A few trucks are weighed by manual peration of the scale. Some difficulty was encountered at first (1961) because of weather effects on the recording system which was installed by Stathmos-Lindell.

Horsens

The 10-tonne weighing scale is located inside the tipping hall, adjacent to the pit and within view of the control-room operator who is also the crane operator and scale operator. The scale is calibrated once per year by the manufacturer. Only the trucks delivering industrial waste are weighed and pay a fee. All others, unweighed, dump free. For the collection and disposal service each household pays a tax. Occasionally truck-loads of sacked residential waste are weighed for a week or so to obtain data from which the residential input can be estimated.

Copenhagen:Amager and West Plants

At each Copenhagen plant arriving trucks proceed to one of the two load cell type of 50 tonne (55 ton) scales manufactured by Philips of Holland shown in Figure P-5a. Drivers produce their universal plastic cards that identify the vehicle owner, etc. This information, along with the gross weight, is fed into the computer, where the tare weight, mailing address, etc. are stored.

Occasionally the plastic cards jam, break, or become lost. In this event, the driver would have to get out of the truck and spend several minutes in the scale house filling out a form. The cards were replaced on an as-needed basis. They have changed the system so that every 6 months all of the plastic cards are changed at once.

At the time of the visit in October, 1977, a particular card would work at Amager, West, and the Hillerod transfer station. An identical Philips system was under consideration for the Roskilde Volund plant as well. In theory, the system could be used throughout Denmark to the advantage of all.

Revelant information is displayed on digital readout devices. The single operator can process 120 vehicles per hour if both scales are used simultaneously. The scales can be used automatically at night when the

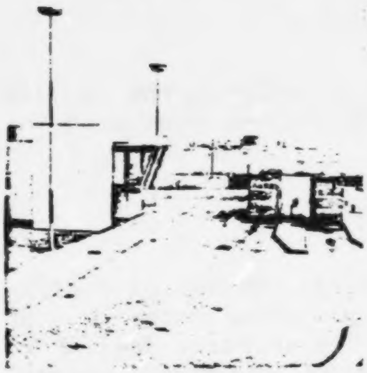


FIGURE P-5a. SCALE HOUSE AND TWO SCALES

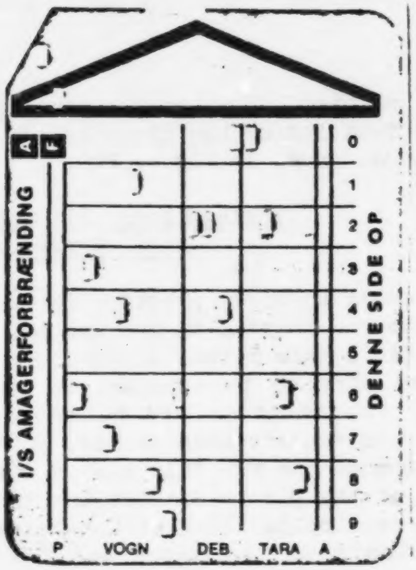

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FIGURE P-5b. PLASTIC CARD

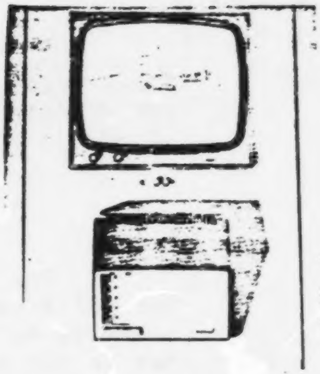


FIGURE P-5c. MONITOR IN CONTROL ROOM OF TRUCK SCALE

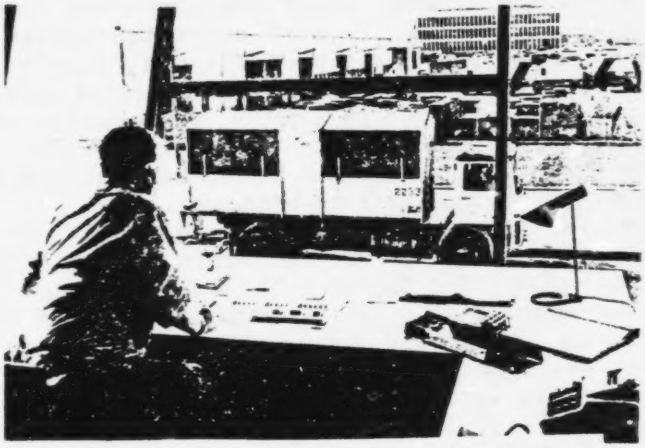


FIGURE P-5d. DIGITAL READOUT IN SCALE HOUSE

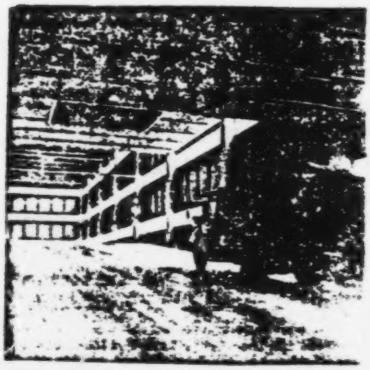


FIGURE P-5e. RAMP TO TIPPING FLOOR

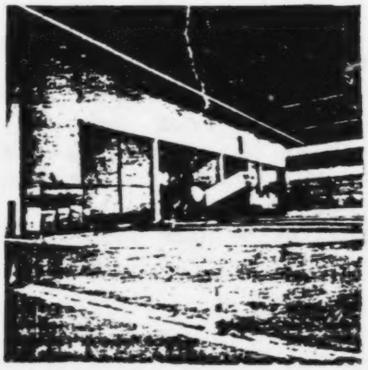


FIGURE P-5f. TIPPING FLOOR

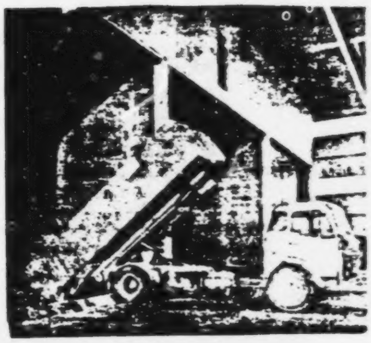


FIGURE P-5g. TIP ARRANGEMENT PERMITTING GOOD CRANE VIEW scale house is unmanned. Opening the plant gate and weighing the vehicles can be controlled from inside the plant at the main control room with use of television cameras shown in Figure P-5c.

Tipping Floor, Pit and Crane
General Comments

The universal European practice for receiving, storing and feeding the solid waste to the funaces is the ancient pit and crane system. To most newcomers to the field this method appears incredibly archaic. However it has so far defied efforts to supplant it with modern conveying equipment. The major barrier to change is the heterogeneity of MSW and its strong tendency to pack and densify when stored. Until economically reliable means are developed to homogenize MSW this status will probably continue.

At most of the plants visited the tipping floor is indoors. Figure P-5f shows the large tipping floor at Copenhagen. At the smaller plants and even the large plants at The Hague and Issy-les-Monlineaux at Paris, the trucks tip while outdoors or are only partially shielded from the weather when actually discharging into the pit.

In all cases, indoors or outdoors, the discharge openings into the pit are covered by power-operated doors. Thus pit odor is kept inside by fresh combustion air flowing through the open doors under the action of the combustion air blowers. In most cases the blowers take the air from filtered air intakes near the top of the pit. Thus air flow is always in and in no case was the odor of refuse detected outside the plants nor in the neighborhood. Figure P-6 is a photo at Deauville of nearly apartments viewed through the open doorway to the tipping floor. At that plant, in addition to the powered exterior door, each of the 4 pit doors is also covered, when not in use, by a powered door.

In most plants the entrance and agress of the trucks to the tipping area is controlled by the scale operator, with a workman on the tipping floor controlling the opening and closing of the pit doors. In a few cases the hydraulically lifted doors are operated by the truck driver.

Usually the drivers are expected to clean up any spilled refuse before they leave and, in general, the tipping floors were free of debris, but not always. The attitude of management toward housekeeping standards was variable and resulted in a very few messy tipping floors. One plant, Wuppertal, made daily use of a large mobile washer and sweeper to keep the tipping floor and adjacent ramps exceptionally clear.

Pit Doors

The most commonly used powered pit door is the multi-hinged door as at Gothenborg, Sweden. A distinct disadvantage of this type is that if several such doors happen to be open at once at a busy time the lifted doors hide much of the pit from the view of the crane operator who is situated directly above the doors. Also such doors projecting into the crane area are very vulnerable to accidental collision with the crane bucket. For these reasons at the new Zurich: Josefstrasse plant will use the more expensive guillotine door when it opens in 1979.

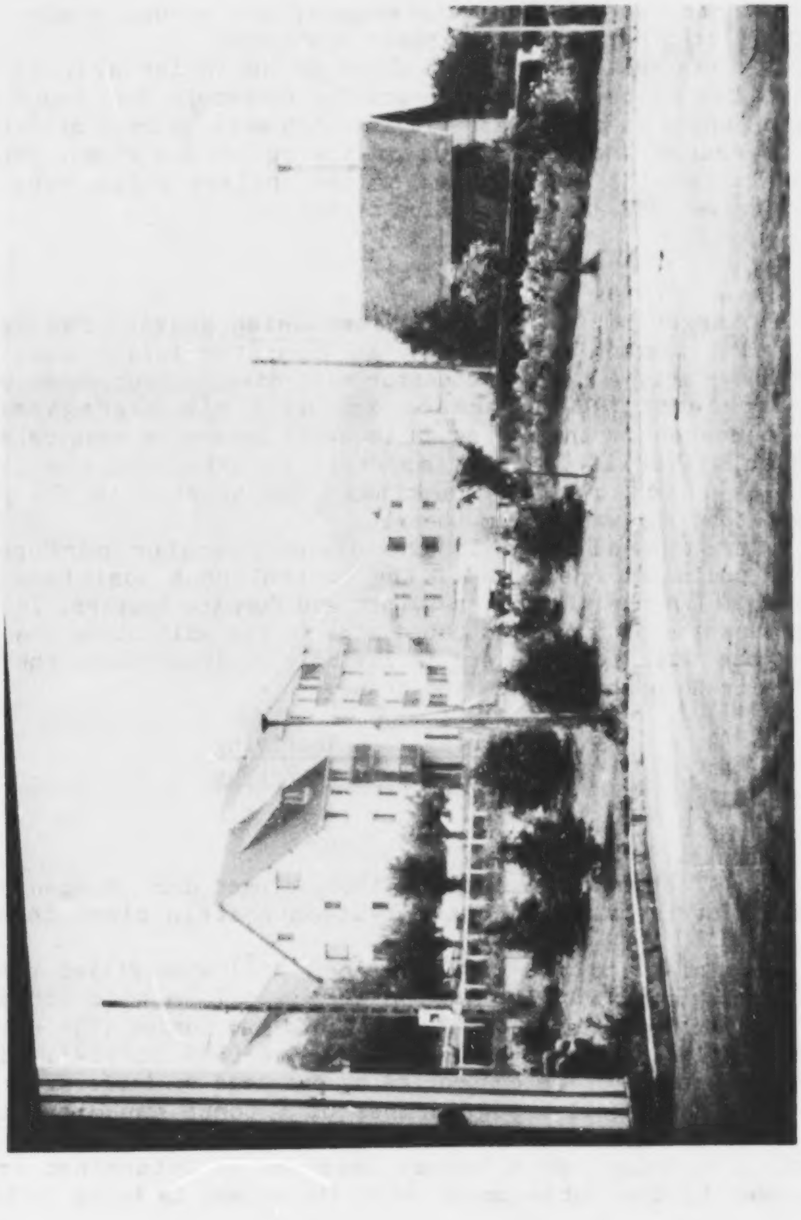


FIGURE P-6. RESIDENCES VIEWED THROUGH TRUCK ENTRANCE AT DEAUVILLE PLANT (Battelle Photograph)

Pit or Bunker

Table P-1 shows the dimensions and capacity of the storage pits at the plants visited. The floor of most pits is below grade. Because of water-table or excavation problems, a few are at grade, in which case the tipping floor is elevated and is reached by a sloping sometimes helical, ramp. Most pit walls are reinforced concrete.

The predominant design philosophy provides a maximum pit storage capacity of 4 to 5 days' operations. Since all of the larger plants usually schedule units to be down for maintenance, the actual storage capacity provides for 5 or 6 days of normal plant operation.

Pit fires are usually controlled by sprinkler systems and water guns controlled by the crane operator. For extremely dry, industrial waste at The Hague, there is a separate pit in which water sprays operate most of the time to reduce the heat value of the refuse as fired. This prevents fires and also avoids overheating of the boilers which were designed originally for wet MSW. See Heat Value of Refuse.

Crane

The larger plants have 2 cranes which provide redundancy. The almost universal comment was the the crane operator is the most important worker in the plant. A skilled operator will divert troublesome bulky items to avoid problems in the furnace and will mix segregated, highly combustible wastes in the pit so as to avoid excessive heat release in the furnace. Also his skill is very important in extending the life of the crane cables which can become kinked and twisted in the process of retreiving batches of waste from the pit.

In most small plants the crane operator performs from a glass-walled podium at one side of the control room positioned so as to provide a view of the tipping area, pit and furnace hoppers. In the larger plants the separate podium is situated high in the wall above the pit often the podium has dual controls and is lavishly equipped above the pit. In no case did the crane operator ride the crane.

Plant Details on Receiving Storing and Feeding Refuse

Werdenberg

Figure P-7 shows the tipping floor, hinged door in open position and pit and crane at the small Werdenberg-Liechtenstein plant in eastern Switzerland.

The main plant pit is 1300 m^3 (1690 yd^3) when filled level with the tipping floor. It is 20m long, 8.5m deep and 7.5m wide (65.6 ft by 27.9 ft by 24.6 ft). It is estimated to hold 800 tonnes (854 tons) at a compressed and settled density of 0.383 tonnes/m^3 (645 lb/yd^3). If fire breaks out in the pit it can be controlled by overhead sprinklers.

There are 2 Von Roll bridge cranes of 5 tonne capacity but only one is needed. A clamshell type of bucket on each crane can lift 1/2 to 1 tonne at a grab. The weight of a bucket load can be determined from the current consumed by the cable motor when the bucket is being lifted at a

TABLE P-1. REFUSE PIT STORAGE VOLUME, DIMENSIONS AND CAPACITIES

	Plant Design Capacity tonnes/ day	Nominal Plant Oper. tonnes/ day	BUNKER VOLUME				BUNKER DIMENSIONS						STORAGE CAPACITY[2] At Packed Density of 645lb/yd^3 (383Kg/M^3)			Days Supply At Full Plant Capacity	Days Supply At Nominal Plant Capacity
			Level M^3	Full yds^3	Maximum M^3	Maximum yds^3	Length M	Width M	Depth M	Length ft	Width ft	Depth ft	Level tonnes	Max tonnes	Tons		
Werdenberg	120	100	1300	1640	--	--	20	7.5	8.5	65.6	24.6	27.9	500	--	550	4	5
Baden-Brugg	200	160	2600	3400	--	--	23.4	8.4	14.1	76.7	27.6	45.3	995	--	1095	5	6
Duesseldorf	1260	960	10,500	13,734	--	--	--	--	--	--	--	--	4022	--	4424	3	4
Wuppertal	1440	1080	10,000	13,080	18,000	23,540	--	--	--	--	--	--	--	6894	7583	5	6
Krefeld	576	576	6,000	7848	9000	11,772	35.0	12.0	--	115	40	--	--	3796	4175	6	6
Paris:Issy	1632	1550	--	--	--	--	--	--	--	--	--	--	--	5000	5500	3	3
Hamburg:SM	1180	--	10,400	13,600	10,400	13,600	54	12	16				3970	--	4370	3	--
Zurich: Hagenholz	1024[1]	--	5000	6540	9000	11,770	--	--	--	--	--	--	1920	3456	2100	3	--
The Hague	1440	1080	10,000	13,080	16,000	20,930	--	--	--	--	--	--	--	6100	6710	4	6
Dieppe	120	63	750	980	--	--	--	--	--	--	--	--	290	--	320	2	5
Deauville	120	--	700	920	--	--	--	--	--	--	--	--	270	--	295	2	--
Cothenberg: Savenas	1080	900	6000	7843	12,000	15,690	--	--	9	--	-- --	30	2300	4600	2530	2	3
Uppsala	348	200	--	--	2400	3140	--	--	--	--	--	--	--	920	1010	3	4
Horsens	120	67	950	1240	--	--	--	--	--	--	--	--	360	--	400	3	5
Copenhagen: Amager	864	864	10,000	13,030	20,000	16,160	48	17	13	157	56	43	6100	12,200	6710	7	7
Copenhagen: West	1152	864	12.500	16,350	25,000	32,700	56	17	13.5	184	56	44	7625	15,250	8390	6	9

(1) Nominal capacity included 2 older units.

(2) This assumed density would apply after several days'storage.

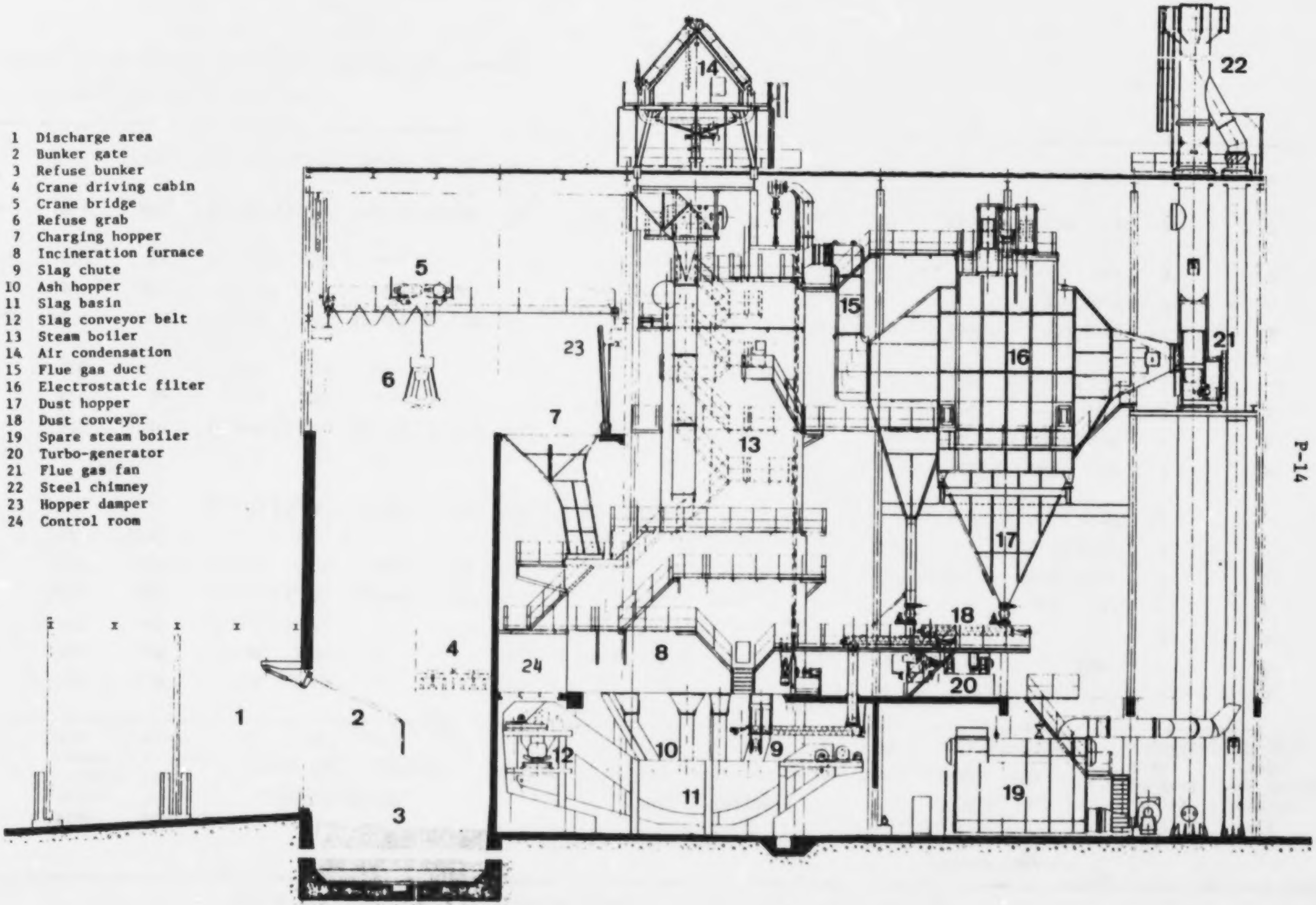

1 Discharge area
2 Bunker gate
3 Refuse bunker
4 Crane driving cabin
5 Crane bridge
6 Refuse grab
7 Charging hopper
8 Incineration furnace
9 Slag chute
10 Ash hopper
11 Slag basin
12 Slag conveyor belt
13 Steam boiler
14 Air condensation
15 Flue gas duct
16 Electrostatic filter
17 Dust hopper
18 Dust conveyor
19 Spare steam boiler
20 Turbo-generator
21 Flue gas fan
22 Steel chimney
23 Hopper damper
24 Control room

FIGURE P-7. OVERALL SECTION INSIDE THE WERDENBERG PLANT
(Courtesy Widmer & Ernst-Alberti-Fonsar)

constant rate of speed. The corresponding weight can be read by the crane operator sitting in the control room.

There were problems due to inexperience during startup. If the crane cables were not kept in tension they would jump the pulleys on the bucket. With careful operation the cables last 2 months. With unskilled operation they last 2 weeks. About 2 hours are required to repair broken cables.

The plant control room also contains the crane operator's perch high on one side of the pit. The room is air conditioned. The crane is semi-automatic in that after the bucket is loaded the crane liftsand positions it over the furnace hopper.

Baden-Brugg

Figure P-8 shows a truck delivering at Baden-Brugg. There are 6 doors. Five are closed. The scale operator can direct truck drivers to alternate tipping bays by the red and green lights above the truck entrance.

The refuse pit storage capacity when level-full is 2600m^3 (3400 yd^3). Assuming a stored refuse density of 0.383 tonne/m^3 (645 lb/yd^3) its storage volume would be 995 tonnes (1095 tons), or about a 4.5-day fuel supply at capactiy operation. The pit is 23.4m (76.7 ft) long, 14.1m (45.3 ft) deep and 8.4m (27.6 ft wide). Fires in the pit can be controlled by means of overhead sprinklers.

The pit is equipped with 2 cranes built by Mars-Uto of 5-tonne capacity each. Each is equipped with a 2m^3 (2.6 yd^3) polyp orange-peel type of grab. The weight of each crane load can be observed by the crane operator on a digital read-out actuated by a strain gage on the crane cable. The operator, whose pulpit is at the end of the pit, records this weight reading manually. Figure P-9 shows the operator and two crane grabs.

An automatic crane stop is provided so that if the crane approaches an open delivery door on the side of the pit the crane is prevented from striking and damaging the open door.

Duesseldorf

Figure P-10 shows the main bunker at this large 5-furnace plant which has a storage capacity of 10,500 m^3 (13,734 yd^3). At a compressed and settled density of 645 lb/yd^3 (0.383 tonnes/m^3), this represents a storage volume of (4022 tons), about 3 days' supply. Fire control is by means of six nozzles at the operator's level plus a spray system.

There are three Schiess cranes (now part of Demag), 120 tonnes (132 tons) each. One crane is stored as a spare on a track in a loft above the boiler room. Also, the crane can be quickly rolled onto this storage track for repairs. One of the two crane operator's posts can be seen on the left in Figure P-10. Both cranes operate during the day, one at night.

Each crane bucket is the polyp type with a capacity of 4 m^3 (141 ft^3). Figure P-11 shows a new bucket in preparation for installation.

For boiler tests, the crane motor electrical input was calibrated in terms of weight lifted. During the tests, this current was recorded continuously. In routine operation, the crane operator records the number of bucket loads charged to each furnace per shift. From this, an approximate average furnace load is calculated.

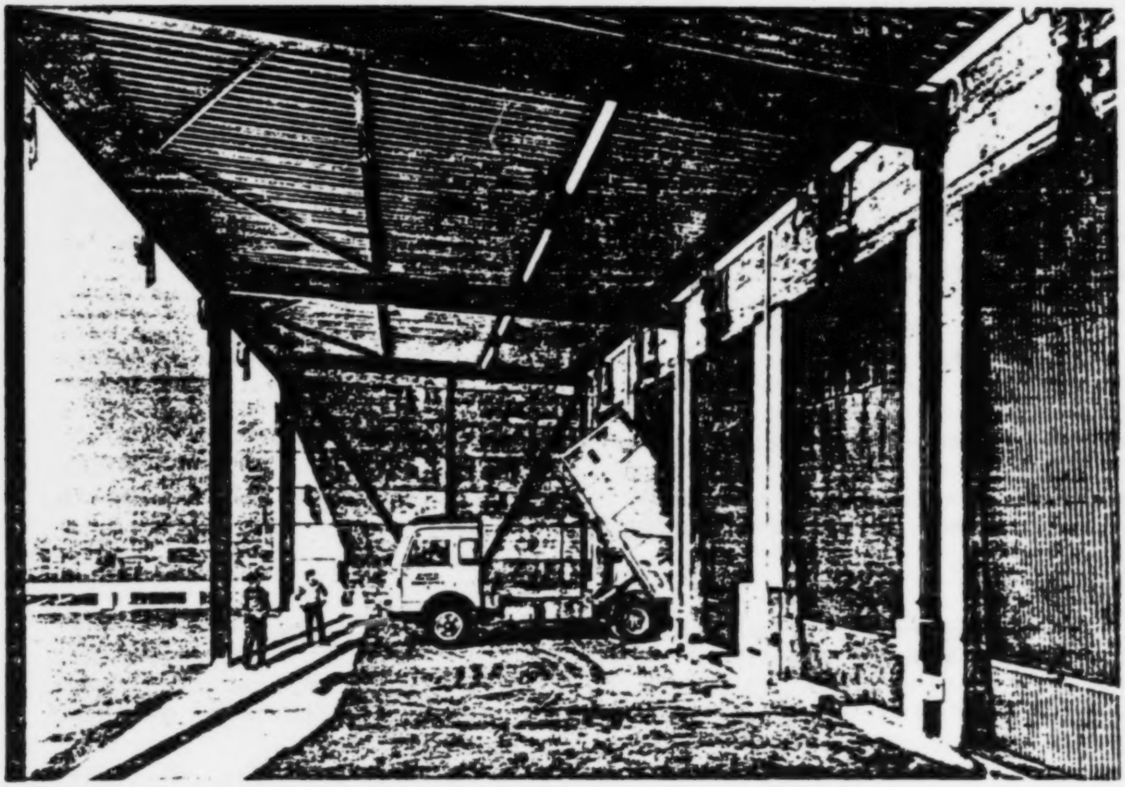


FIGURE P-8. TRUCK DELIVERING WASTE TO THE PIT AT BADEN-BRUGG.
THE PIT DOORS ARE HYDRAUCIALLY OPENED.
(Courtesy Region of Baden-Brugg)

P-16A

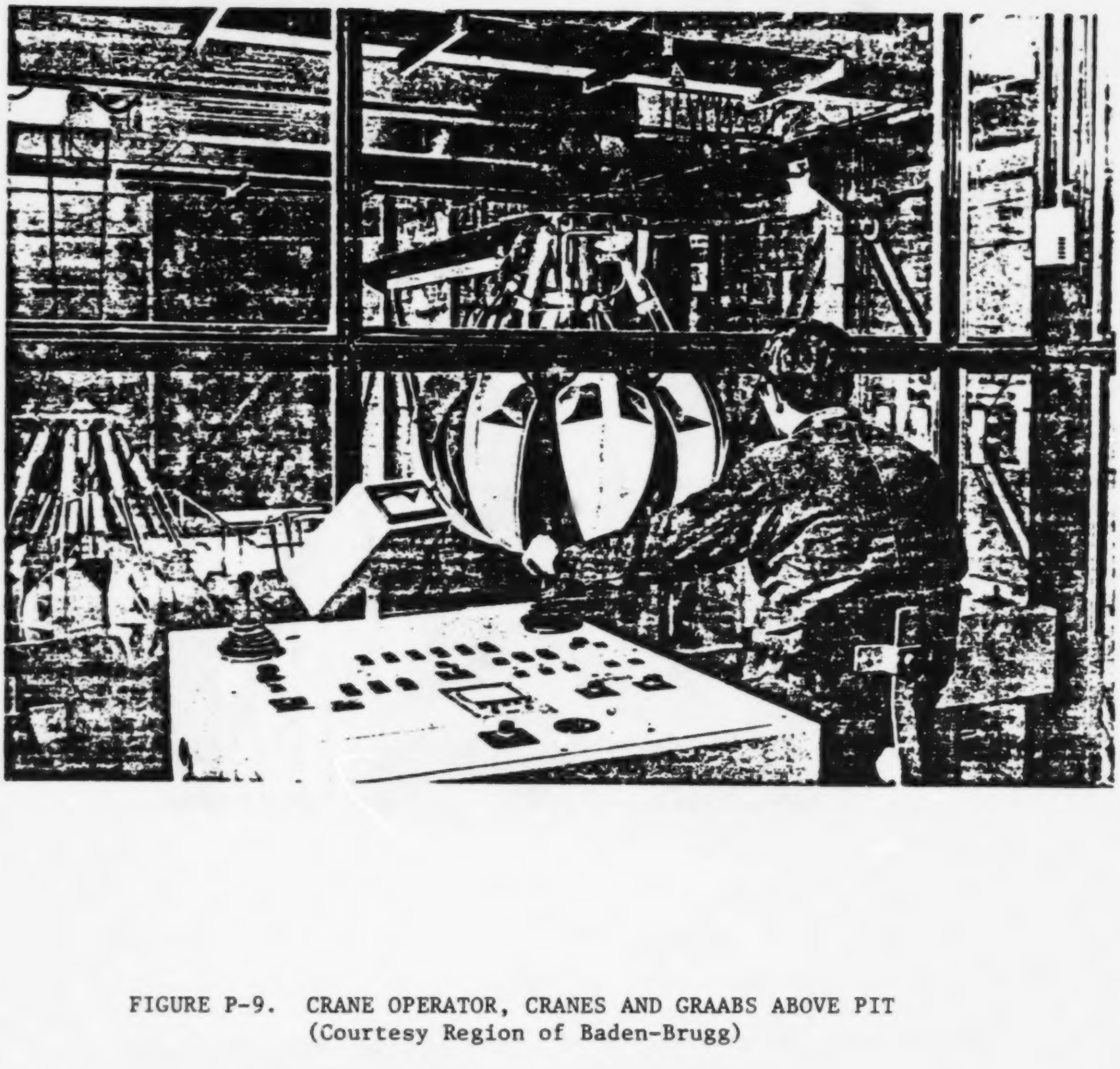


FIGURE P-9. CRANE OPERATOR, CRANES AND GRAABS ABOVE PIT
(Courtesy Region of Baden-Brugg)

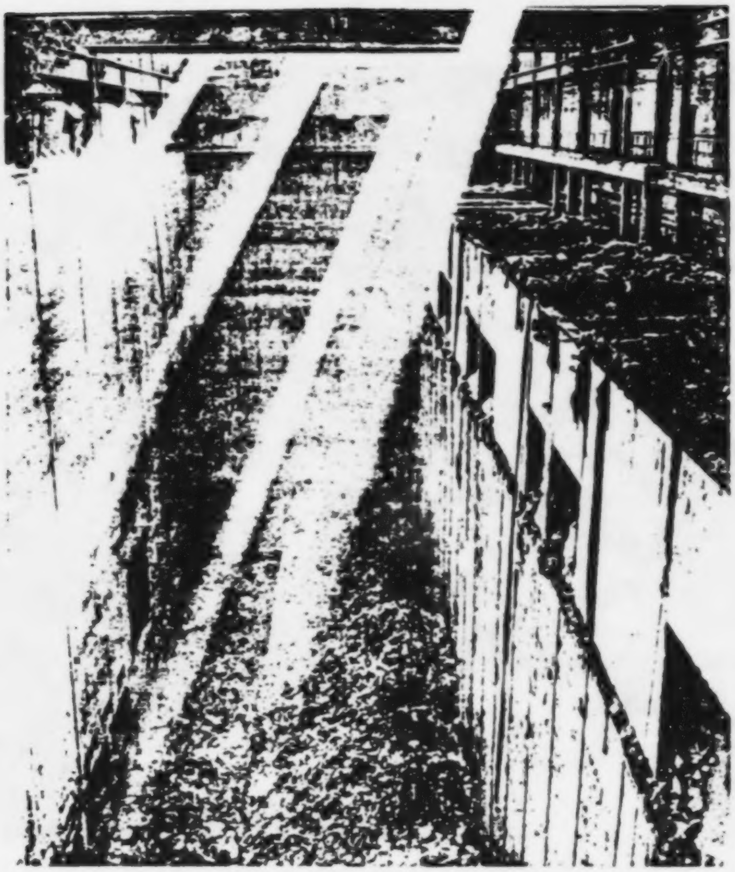


FIGURE P-10. MAIN STORAGE PIT. THERE ARE TWO CRANE OPERATORS OPERATING PULPIT FOR ONE IS AT UPPER LEFT AT DUESSELDORF. (Courtesy Vereinigte Kesselwerke AG)

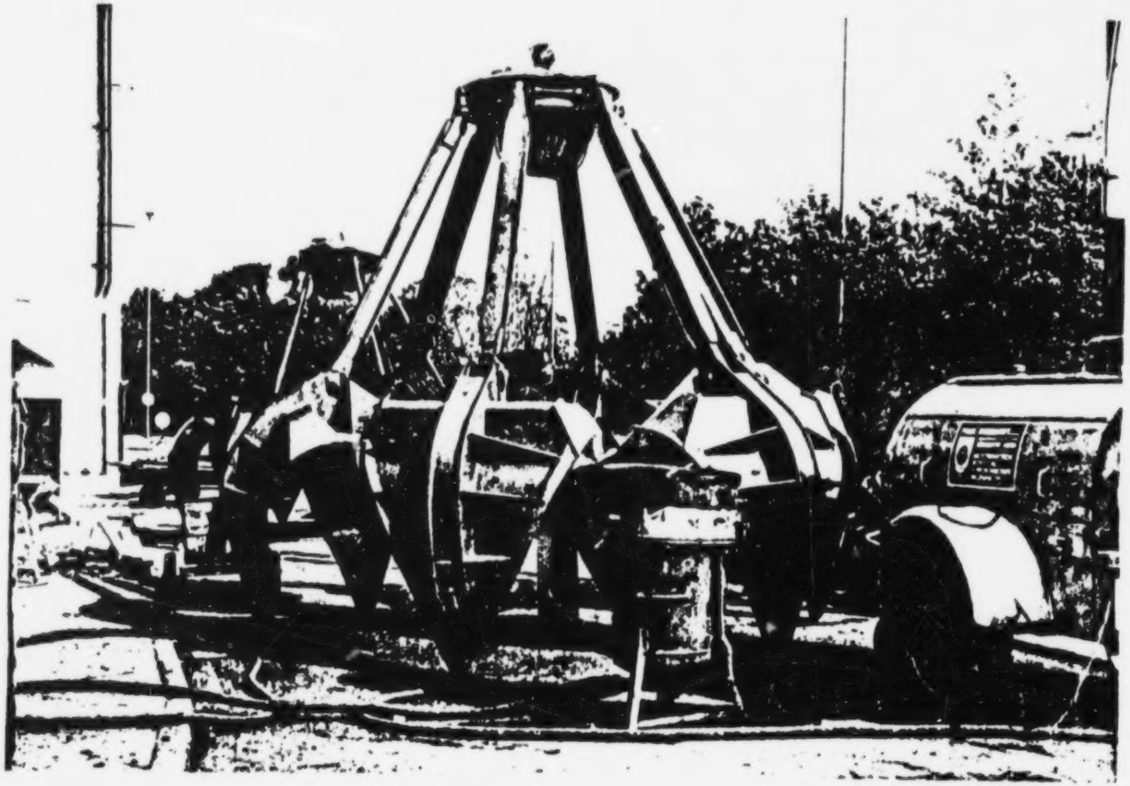


FIGURE P-11. NEW POLYP BUCKET BEING PREPARED FOR INSTALLATION AT DUESSELDORF (Battelle Photo)

Wuppertal

The refuse pit has a level-full capacity of 10,000 m^3 (13,078 yd^3). At a compressed and settled density of 645 lb/yd^3 (0.383 tonnes/m^3), this represents a maximum storage volume 6894 tonnes (7583 tonnes/m^3), about 6 days' supply based on three-unit operation with one unit held as spare, 5 days at full plant capacity.

There are two Ridinger cranes (no longer being manufactured) of 10 tonnes each. There are two control cab locations, one on either wall of the pit. But only one cab and one crane are now in use; hence, there is one operator per shift plus a reserve operator.

The polyp-type crane buckets lift approximately 6 m^3 (7.8 yd^3). Replacement polyps will have a capacity of 7 m^3 (9.2 yd^3).

The crane operator can remotely control one of two water nozzles from each control cab for supression of pit fires. These have not been needed to date.

To provide an approximate measure of refuse fired, there are four pressure transducers on the bucket with digital readout and recording in the cab. The totals are tabulated for each shift.

After the crane operator loads a bucket and selects a desired hopper, the crane travel to a position above that hopper is automatic but the operator must then press the unloading button.

The polyp is serviced once per month. The crane cables are rotated every 3 months and they last 6 months.

Paris:Issy

At the Issy-les-Monlineaux plant, nine (9) doors open to the 7000 m^3 (9,160 yd^3) pit that holds 2,700 tonnes (2,950 tons) when level. When refuse is stacked above the tipping floor level, 5,000 tonnes (5,500 tons) can be stored. Therefore, 3 to 4-days' waste can be stored.

There occasionally is spontaneous combustion when 2 to 3 days supply accumulate the pit. Another source of fires is sparks from construction welding to repair the crane or bucket and torch cutting to destroy large bulky refuse.

For small fires, the truck-tipping floor mounted hoses are sufficient. The local fire department is called out for large fires.

The traveling bridge cranes are inspected each morning. Ten electrical contracts must be maintained. Repairmen can replace contacts until too many have failed. It is the welding of these contacts that produced sparks causing several pit fires. Then the entire assembly must be replaced.

"If future designers wish to avoid downtime" plant officials recommended "they should consider two independent bridges where each has individual circuits and are on different elevations."

The polyp bucket has two kinds of cable. One U-shaped strand lifts and lowers while the other U-shaped strand opens and closes the bucket. The cables last anywhere from 2 days to 1 month.

Cables are inspected every Friday to avoid calling in repairmen over the weekend. Even this does not insure failsafe weekends. If a cable is fraying or has kinks near the bucket, the cable is shortened by the operatins staff, not maintenance. Four people often spend 3-4 hours repairing the opening-closing cable. Two people can repair the lifting and lowering cable in 1-1/2 hours.

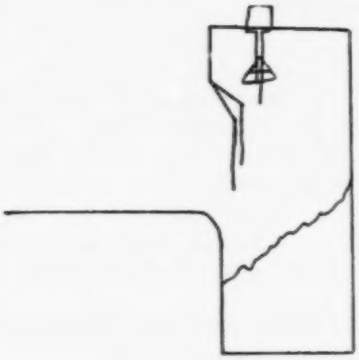
The crane is equipped with a Bourdon dynamometer to measure weight. This load cell measures current in amperes, in the static position, just above the hopper and immediately before discharging. The crane has a capacity of 10 tonnes. The buckets are 5m^3 (6.5 yds^3) and can carry up to 3.5 tonnes (3.9 tons).

Zurich

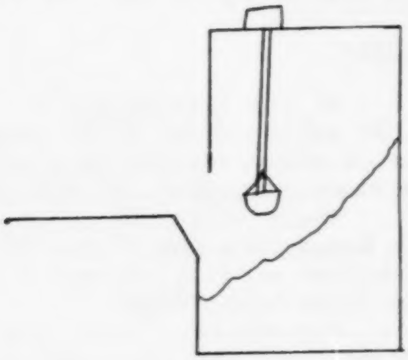
The refuse pit at Hagenholz holds about 5,000 m^3 (6450 yds^3) or 1920 tonnes (2100 tons) when filled to the level of the tipping floor assuming a density of 0.383 tonnes/m^3 (645 lb/yd^3). When three or four doors are closed refuse can be piled up to 9,000 m^3 (11,770 yds^3). During our visit, material was so piled up that the closed doors were bowed outward.

There are fire hoses above the pit to fight small fires. Once, since 1969, they did have to call the fire department.

The two three-tonne (3.3 ton) cranes manufactured by Haushahn of Stuttgart are double bridge. The crane operator in the traveling cab is often faced with difficulty in judging the type of waste available (for calorific value and bulky items) because of the obstructed view of the opened, bended knee door that extends out into the refuse pit. As a result, the new plant at Josefstrasse will have vertically rising guillotine doors.



Existing Hagenholz



New Josefstrasse

Josefstrasse will have the semi-automatic crane feature that accurately places the bucket over the hopper. (The Hagenholz system is manually operated only). Hagenholz uses the less expensive clam shell buckets. However, at Josefstrasse, polyps will be used. The clam shell, while large in volume capacity does not compact well and is itself very heavy. The polyp, however, is lighter, and can compact more. This results in a bigger refuse load lifted per lift. The crane capacity at Hagenholz is 38.7 tonnes (42.6 tons) per hour while at Josefstrasse it will be 44 tonnes (47.4 tons) per hour.

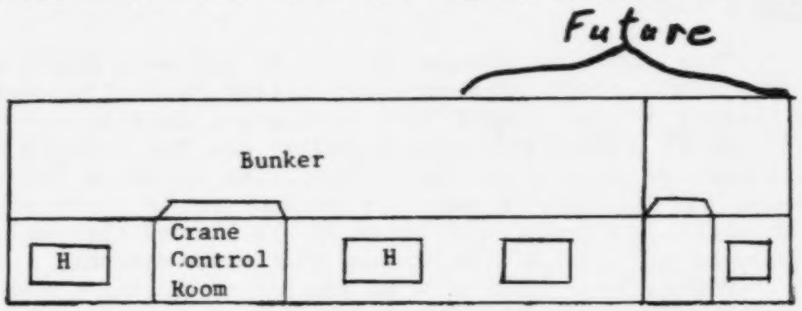
The load cell on the crane failed and has intentionally not been repaired as stated by one official:

> "We don't care how much refuse we are burning. Our concern is how much steam we are producing. Hagenholz is an energy plant and not primarily a refuse disposal plant. If we repair the load cells, people may begin paying too much attention to refuse burning and not enough to energy production."

Hamburg

At the Stellinger-Moor plant the pit is 54m (177 ft) long, 16m (52 ft) deep and 12m (40 ft) wide. When refuse is stacked above the tipping floor level, 350 tonnes (3850 tons) can be stored providing 3 to 4 days' supply. Level storage is about 2500 tonnes (2750 tons).

The cab is centered between and slightly above the two hoppers as shown below.



The location of hoppers for two future units is shown.

The hinged metal doors open inward over the pit. Because of the door the crane operator has difficulty seeing what is coming into the pit as it is falling in. He needs to observe this to better determine how the waste should be mixed. Often, but not in Hamburg, this obstacle is overcome by having the crane control room located on the sides of the refuse pit.

The traveling crane at Hamburg was manufactured by FA. Lavis.

Formerly, the crane cables had to be replaced every 3 weeks. Often, the bucket will settle in the pit at a 30 degree to 45 degree angle instead of flat. This causes the cable to catch in between the claw and bucket. Strand breaking can then occur. In other cases, the operator may let the cable unwind, causing the cable to kink, come out of the trolley, or snag in some way thus leading to a breakage.

One of the plant employees (perhaps motivated by the pay incentive program of "more steam means more pay") came up with the idea of built-in guide shields. This has improved the situation and 3 months (instead of 3 weeks) in the average cable life.

The polyp has lasted longer than expected and was replaced after 4 years. Now, the plant has a new Landers polyp in storage that is only one-half the weight of the existing polyp. This will be used eventually to replace the second polyp.

The plant staff relies more on the crane scales than the truck scales. Four load cells are mounted on the crane. Readings are automaticaly recorded in the main and the crane control rooms when the polyp is hovering over the hopper. They have no problems with the load cells themselves.

However, there are occasional automatic recording functions that fail and recordings must be made manually.

An unusual item in the pit area is the special closet for humans that can be quickly attached to the crane and lowered into the pit. On separate occasions, a truck driver and a pit floor controller were pushed into the pit by backing-up trucks. The men were rescued from the pit with this closet.

In a discussion of polyp versus clam shell advantages, the Martin representative noted a perference for the more expensive polyp in large plants. The clam shell compressing density is about 300 kg/m^3 (500 pounds/yd^3) compared to about 480 kg/m^3 (800 pounds/yd^3) with the polyp.

The Hague

This plant is unusual in that it has two bunkers: a large one of about 10,000 m^3 (13080 yd^3) capacity (level full) for community refuse which, with 4 of the hinged lift type doors closed, can be piled up to about 16,000 m^3 (20,930 yd^3) plus a smaller one for private haulers which often receives mainly bulky refuse. The tendency for the privately delivered refuse in the smaller bunker to be very dry and highly combustible is so great that water sprays located high on the bunker wall are turned on much of the time to keep that waste dampened.

Figure P-12 shows a cross section of the Hague plant with one pit door hinged outward into the bunker.

If four of the main bunker doors are closed, the estimated storage capacity is about 6100 tonnes (6700 tons) at a packed density of 0.383 tonnes/m^3 (645 lb/yd^3) supply for three furnaces.

Figure P-13 shows one of the two crane control rooms high on the outside of the main bunker wall controlling one of the two cranes. Usually only one crane operates at a time. The other smaller bunker is served by one crane controlled by an operator riding the crane in a cab. Each of the main cranes, made by Heema of Holland, is of nine tonne capacity carrying a polyp-type bucket of 4 m^3 each. Fire control in the main bunker is by both fire hose and fixed water spray. To obtain a measure of firing rate, the operators record the number of buckets charged to each furnace per hour.

Figure P-14 shows a slanted mirror located above one of the furnace hoppers which enables the crane operator ot observe when a hopper needs fuel. Figure 15 shows a polyp discharging to a hopper.

Where the scale operator observes non-combustible bulky wste, such as steel appliances being delivered, he directs the driver to unload the objects in a walled-in yard near the new waste processing facility for later processing and relcamation and disposal.

Dieppe-Deauville

The Dieppe plant pit has a capacity when level full at 750 m^3 (980 yd^3). Above the pit is a single 4.25 tonne (4.7 ton) crane, built by Reel, carrying a 1.5 m^3 (2 yd^3) clam shell bucket. The Deauville pit capacity is 700 m^3 (920 yd^3). At both the Dieppe and Deauville plants, the crane is controlled from the control room, a common feature to minimize manpower needs at small plants in Europe.

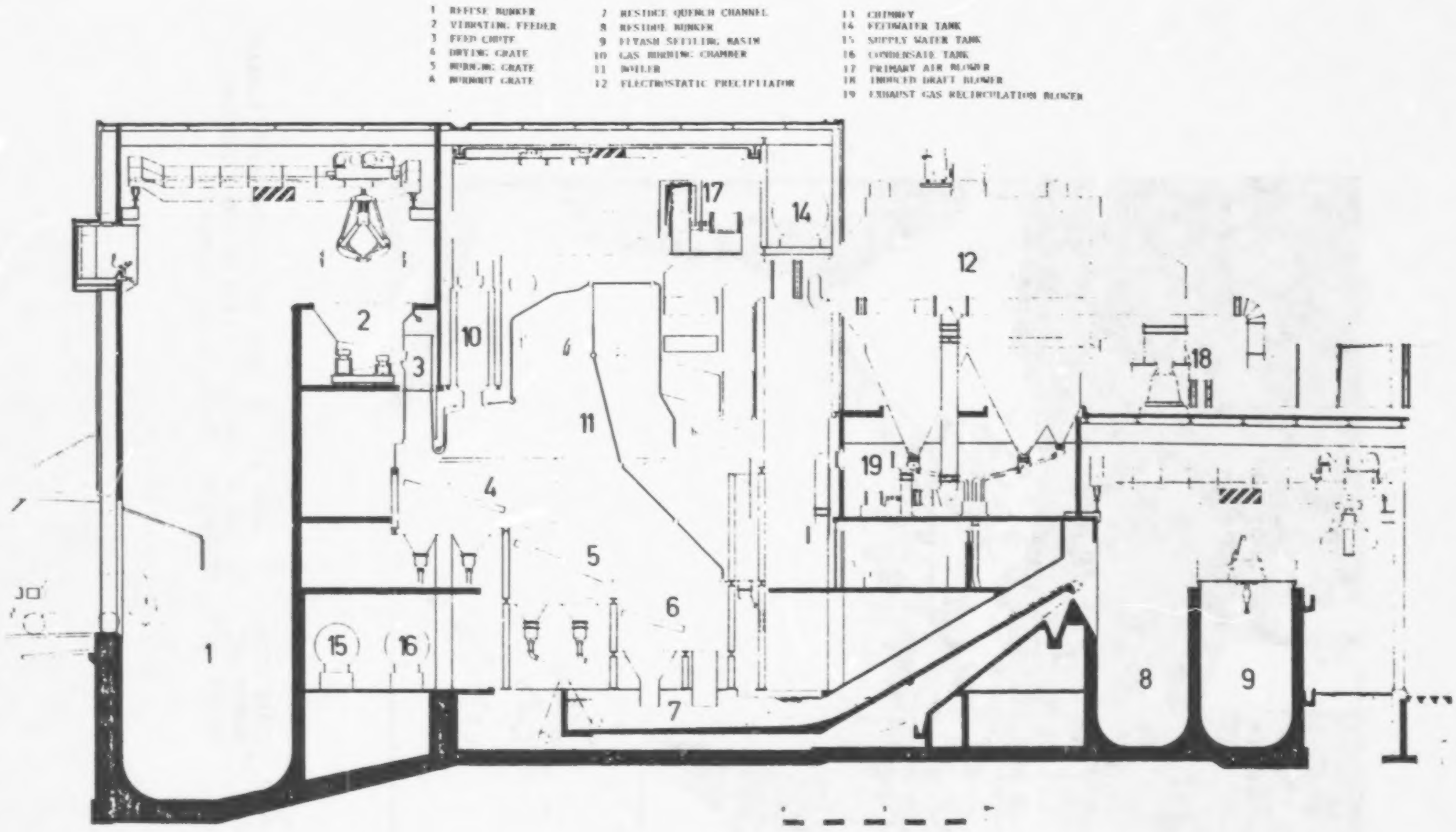

1 REFUSE BUNKER
2 VIBRATING FEEDER
3 FEED CHUTE
4 DRYING GRATE
5 BURNING GRATE
6 BURNOUT GRATE
7 RESIDUE QUENCH CHANNEL
8 RESIDUE BUNKER
9 FLYASH SETTLING BASIN
10 GAS BURNING CHAMBER
11 BOILER
12 ELECTROSTATIC PRECIPITATOR
13 CHIMNEY
14 FEEDWATER TANK
15 SUPPLY WATER TANK
16 CONDENSATE TANK
17 PRIMARY AIR BLOWER
18 INDUCED DRAFT BLOWER
19 EXHAUST GAS RECIRCULATION BLOWER
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FIGURE P-12. CROSS-SECTION OF BOILER SYSTEMS, 1-3 THE HAGUE
(Courtesy of Gemeentelijke Reinigindienst)

FIGURE P-13. CRANE OPERATOR'S CABIN AT THE HAGUE PLANT WITH EMPTY FURNACE HOPPER AND A PORTION OF THE FLOOR PLATE OF THE VIBRATING FEEDER IN THE FOREGROUND (Battelle Photograph)

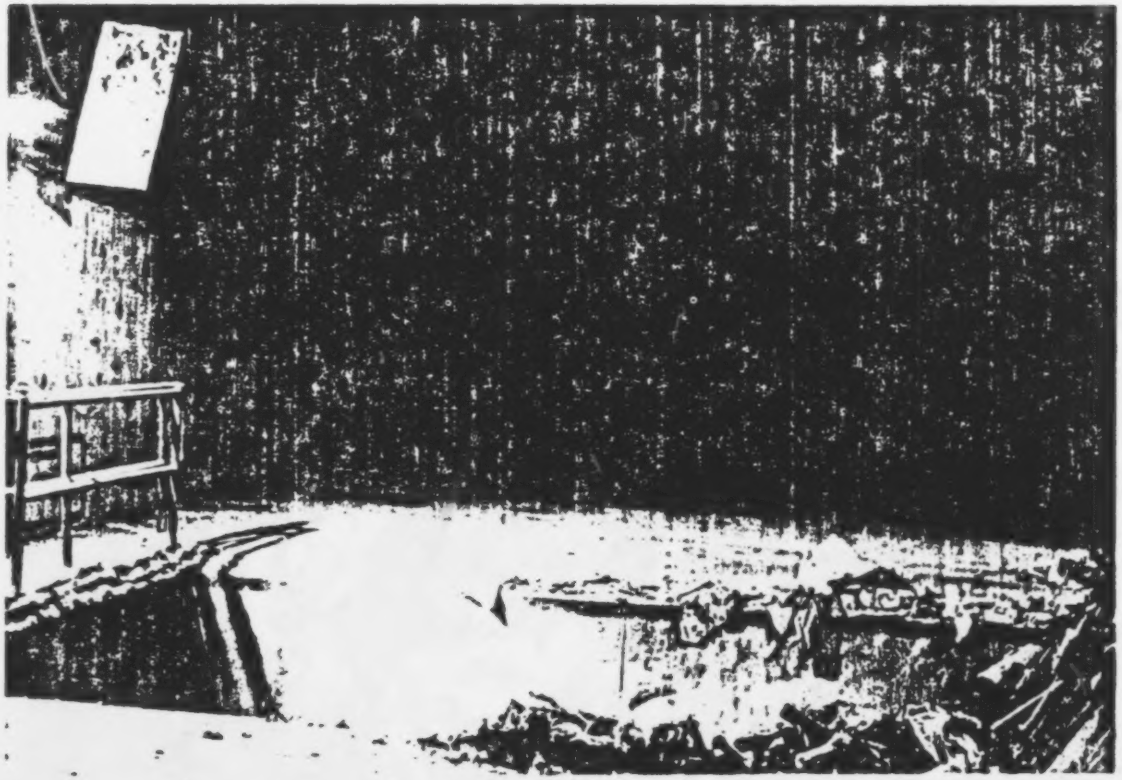

FIGURE P-14. MIRROR ABOVE A FURANCE HOPPER TO ENABLE CRANE OPERATOR TO DETERMINE WHEN THE HOPPER NEEDS TO BE REPLENISHED - THE HAGUE PLANT (Battelle Photograph)

FIGURE P-15. POLYP BUCKET DROPPING A CHARGE OF MUNICIPAL REFUSE INTO A FURNACE HOPPER AT THE HAGUE PLANT (Battelle Photograph)

At Deauville, it has been found that lack of a spare crane is a distinct disadvantage when crane repairs were needed during the summer period, when maximum operation is needed. At Dieppe, the crane cables needed replacement after 1 year due to numerous startup problems in learning to operate the crane in such a way as to minimize cable damage. The new cables, made by Casar especially for the Dieppe plant, are automatically lubricated and are formed of thick wires inside and finer ones outside which are wound alternately in opposite directions to avoid twisting.

At Dieppe, the crane lifts a load and automatically positions the bucket above one or another system of the two furnace hoppers. At Deauville, a similar automatic control system has been temporarily by-passed because the bucket damaged a railing near the hoppers. Also at Deauville, the winter load is so light that several days are required to accumulate enough refuse to support one furnace operation. Thus, some refuse is stored so long that fermentation begins in the pit. The resultant vapors generated are corrosive when they condense on the electrical control contacts. This has caused control failures.

The lightweight cellular concrete pit walls at Dieppe are reinforced by steel columns to withstand occasional impact from the loaded bucket.

At Dieppe, there are five temperature sensors at door height, above the pit to detect pit fires. Small pit fires are handled by using the clam shell bucket to lift the burning material into one of the furnace hoppers. Larger fires are controlled by internal or external (city) fire-fighting equipment. When a temperature sensor detects a temperature rise, it actuates a recording which announces, "There is a fire in the pit".

Gothenburg

Figure P-16 shows a transfer truck backing toward an open pit door to which the driver has been directed by signal lights. The tipping floor control room is in the ceiling as shown at the upper right of the photo.

The pit extends 9 m below the tipping floor. It holds approximately 6,000 m^3 (7,843 yd^3). By closing half of the 14 bunker doors and piling the waste high against the opposite wall, the storage capacity can be doubled to 12,000 m^3 (15,690 yd^3). At a packed density of 645 lb/yd^3 (0.383 $tonnes/m^3$) the maximum storage is 4600 tonnes.

The pit is served by two bridge cranes built by Kone with capacities of 7.2 and 4.8 tonnes. Each has a polyp-type bucket of 6 m^3 (7.8 yd^3) capacity.

Figure P-17 shows the pit with two of the 14 doors open to receive waste. The two crane operators can be seen in the glass walled podium in the upper right. Beneath them is a platform supporting a high-pressure water cannon which can inject water at 1 m^3/sec for control of pit fires. Because of a dangerous fire when two drums of solvent were cut open in a shear, new foam nozzles have been added at the pit sides which can cover the pit with foam 1 m deep in 10 minutes.

The weight of refuse in each bucket load is read from two calibrated watt meters on the cranes with digital readout in the crane podium and readout and recording in the control room. The total weights are

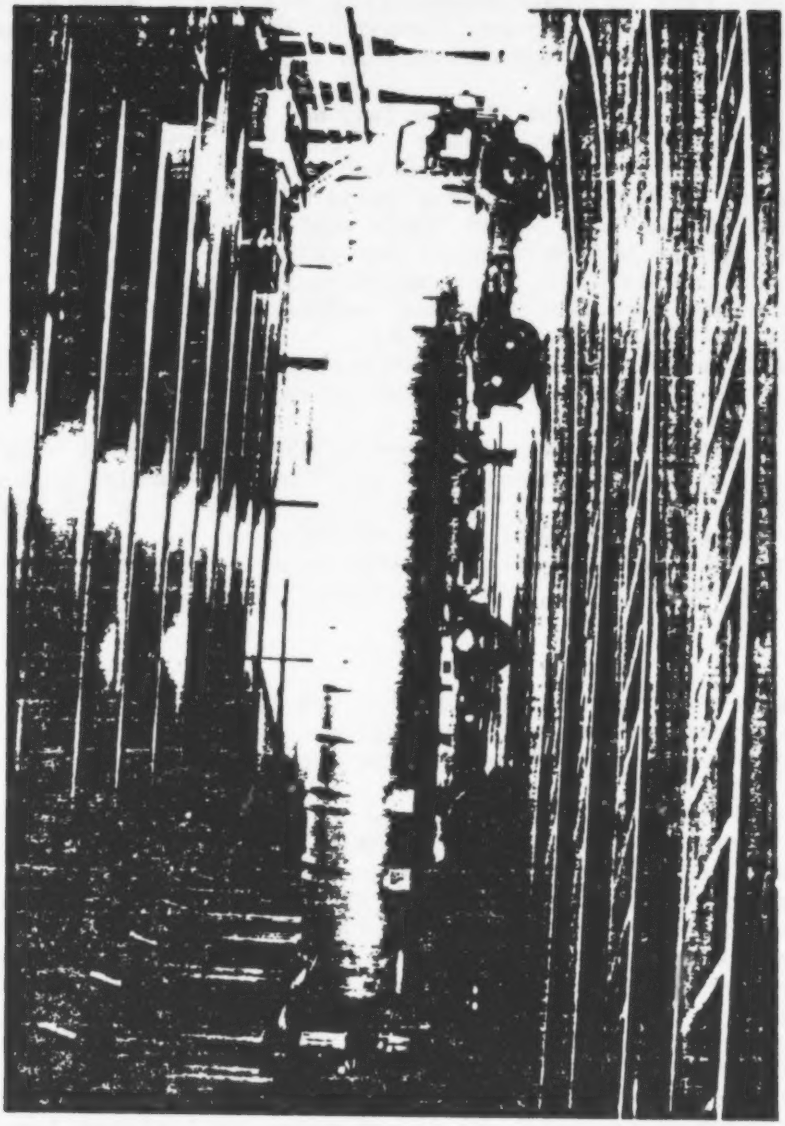

FIGURE P-16. TRANSFER TRUCK IN UNLOADING POSITION AT THE GOTHENBURG SAVENAS PLANT (Battelle Photograph)

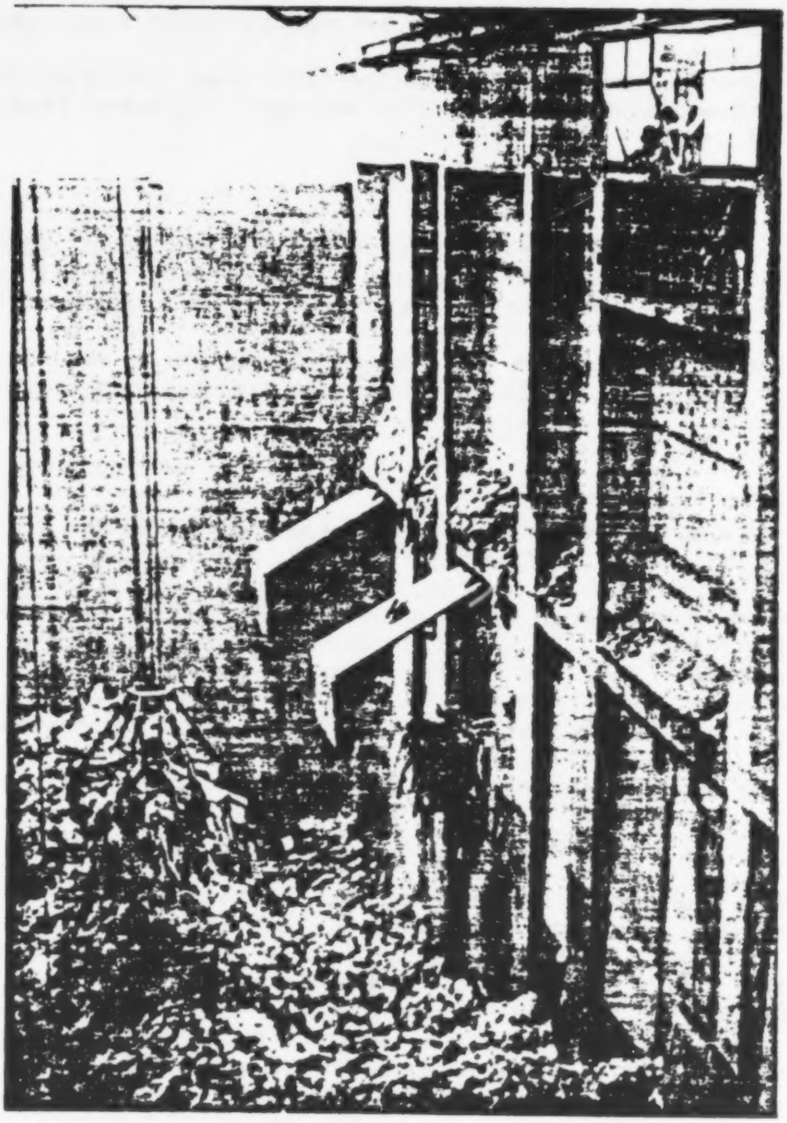

FIGURE P-17. REFUSE PIT WITH 2 OF THE 14 DOORS OPEN TO RECEIVE REFUSE AT THE GOTHENBURG SAVENAS PLANT (Battelle Photograph) checked frequently against the truck scale totals. The watt-meter weights are claimed to be accurate within 5kg (11 lb).

Consideration is being given to an unusual energy recovery scheme: the crane cables would be braked electrically when lowering a load to the feed hopper. The staff estimates that this could generate enough electricity to earn 2,000 S.Kr. ($400) per month, which could pay for the system in 10 years.

To reduce crane cable wear,the cable drums have been enlarged to 24 times the wire diameter and wire size has been increased from 23 to 27 mm (0.9 to 1.1 in).

Uppsala

The maximum refuse storage volume of the present Uppsala pit is 2400 m^{3}h (3140 yd^3). At a packed density of 645 lb/yd^3 (0.383 tonnes/m^3) this provides for 920 tonnes, or about a 2 1/2 day supply at fill plant rating.

Figure P-18 shows the exterior ramp which was added to the Uppsala plant in 1971 to enable operation with a deeper bunker for greater storage capacity.

Horsens

The control room operator at Horsens also operates the crane and weighing platform which is adjacent to the pit. The operator has full view of all of this area through a large window overlooking the pit which is 9 m (30 ft) deep and has a total volume of 950 m^3 (1240 yd^3). It can hold about 360 tonnes a 3-day supply. It is divided into two equal volumes, each 7.7 by 7.2 m (25 by 23.5 ft). In this way,the industrial and residential wastes can be separated. This enables the operator to mix them in appropriate proportions as he operates the crane to fill the single furnace hopper. See Figure P-19. The industrial pit is nearest the operator as it requires close scrutiny to enable the operator to control the mixture fired.

Provisions for Bulky Refuse

Many plants have shears to reduce the size of bulky combustible refuse such as furniture. The shear is usually fed by the crane and discharges to the pit. However, a shear is one more item for maintenance and a few plants have discontinued using their shear.

Figures P-20a and P-20b show a common type of shear made by Van Roll. The specification for a typical shear of this type is as follows:

Max. throughput per hour	up to 200 cu.yards/150 m^3 (depending on the bulky waste, and the way of feeding)
Size of feed opening	118" x 134" / 3 m x 3,4 m
Max. capacity of the shear in open position	10 cu.yards / 8 m^3
Width between the shear beams	12" / 310 mm
Power of driving motor	45 kW
Average power	

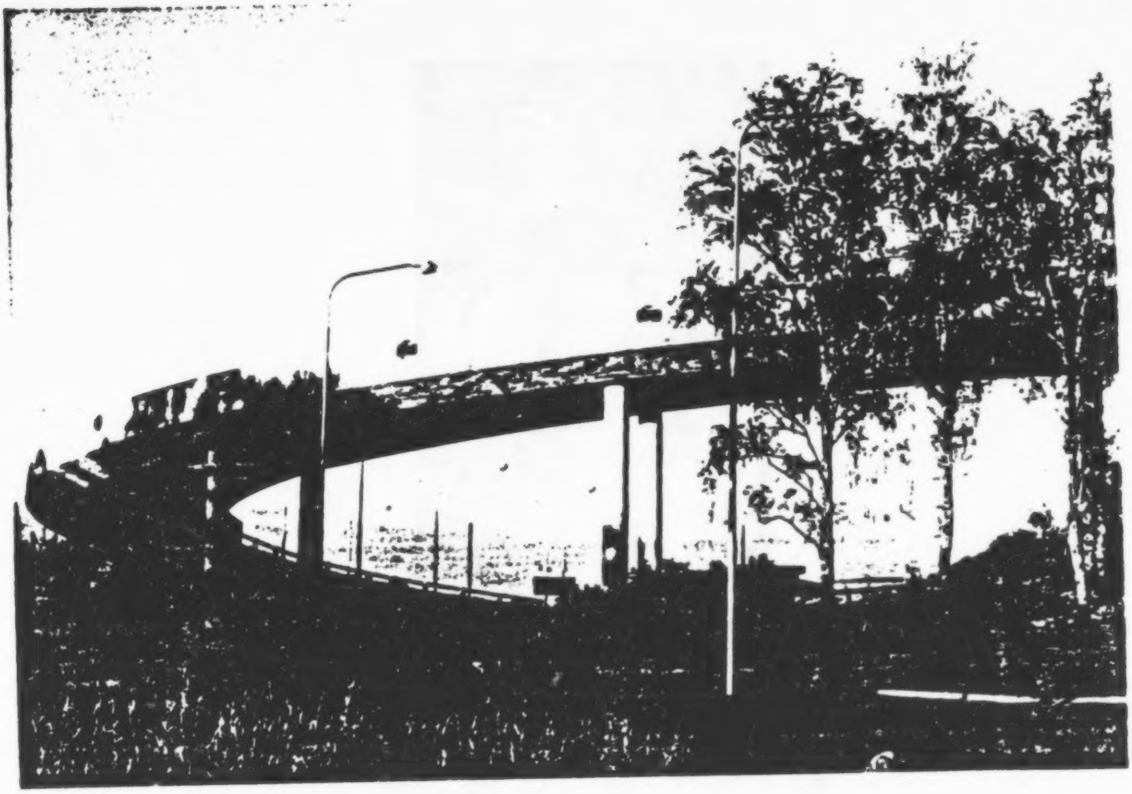

FIGURE P-18. TRUCK ENTRANCE RAMP TO UPPSALA. THIS WAS ADDED IN 1971 TO ENABLE OPERATION WITH A MUCH DEEPER BUNKER WHICH MORE THAN DOUBLED REFUSE STORAGE CAPACITY (Battelle Photograph)

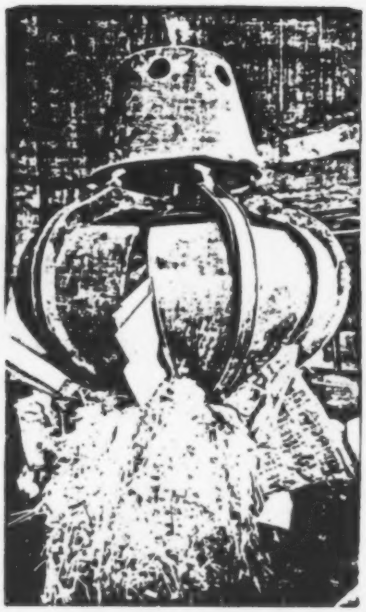

FIGURE P-19. PHOTO SHOWS POLYP GRAB WITH HEAVY CONCENTRATION OF PLASTIC WASTE FROM THE SEPARATE COMMERCIAL AND LIGHT INDUSTRIAL WASTE PIT AT HORSENS (Courtesy of Bruun and Sorensen)

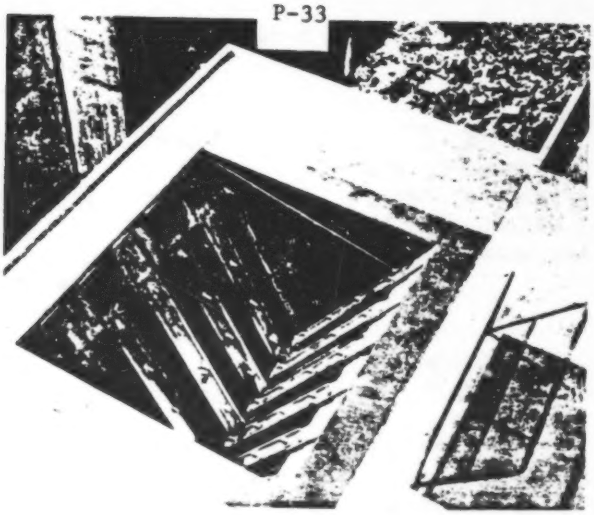

FIGURE P-20a. VON ROLL SHEAR OPENING AT ZURICH: HAGENHOLZ (Courtesy City of Zurich)

FIGURE P-20b. SCISSORS-TYPE HYDRAUCIALLY DRIVEN SHEAR ADJACENT TO HOPPER 4 (Courtesy of Bruun and Sorensen)

consumption	approx. 35 kW
Max. pressure in the hydraulic system	2850 p.s.i. / 200 bar
Total weight of unit	62 tons
Cooling water	1000 liters/hour, of pure quality; static head at entrance to cooler minimum 5 metres, maximum 10 metres
Average time for one working step	approx. 50 sec.

The bulky waste shears (see Figure P-21) operate like multiple sissors, cutting and crushing the bulky refuse between its shear beams. Seven fixed and six moveable shear beams are connected at their lower end through shaft and bearings. Each beam is equipped with double edge blades of highly wear-resistant allow steel which can easily be turned once and reused. The moving beams are arranged in two groups of three, each group being opened and closed by a hydraulic working cylinder.

The sheared material falls through the spaces between the fixed and shear beams and down into the pit. The crane operator must then carefully distribute this usually higher calorific waste over the entire pit.

The unit operates either fully or semi-automatically, with remote-control by the crane operator. Control can otherwise be exercised at the main control panel installed near the hydraulic power unit. A preset pressure switch set at a force of 75 tonnes (120 bars) provided in the hydraulic circuit and combined with a back-up pressure relief valve, limits the maximum thrust exerted by the hydraulic rams. When the limit is reached, the forward thrust stops and the six moveable shears retract so that more refuse can fall into the V-shaped hopper. Thus, the unit is protected against damage when the shearing resistance should grow too high.

A distinct advantage of the Von Roll scissors shear is that it can operate automatically without an attendent. Compared with the many problems of size reduction equipment (jamming, explosions, fires, breakage, wear, etc.), this shear has excellent operating results in most of the visited plants.

Details of Bulky Refuse Handling Methods

Werdenberg-Liechtenstein

At Werdenberg there is no provision for procesing bulky waste. Instead, the crane operator is instructed to crush bulky items, up to 2m by 2m, (6.5 by 6.5 ft) in the pit by dropping the 3-ton grapple on the object. Large metal objects are lifted out and set aside for recycling which, in 1976, totalled 172 tonnes.

Baden-Brugg

Originally the Baden-Brugg plant was equipped with a Hazemag hammermill shredder adjacent to the refuse pit to break up bulky refuse. However, in 1972 owing to the need to replace the shredder bars and re-weld

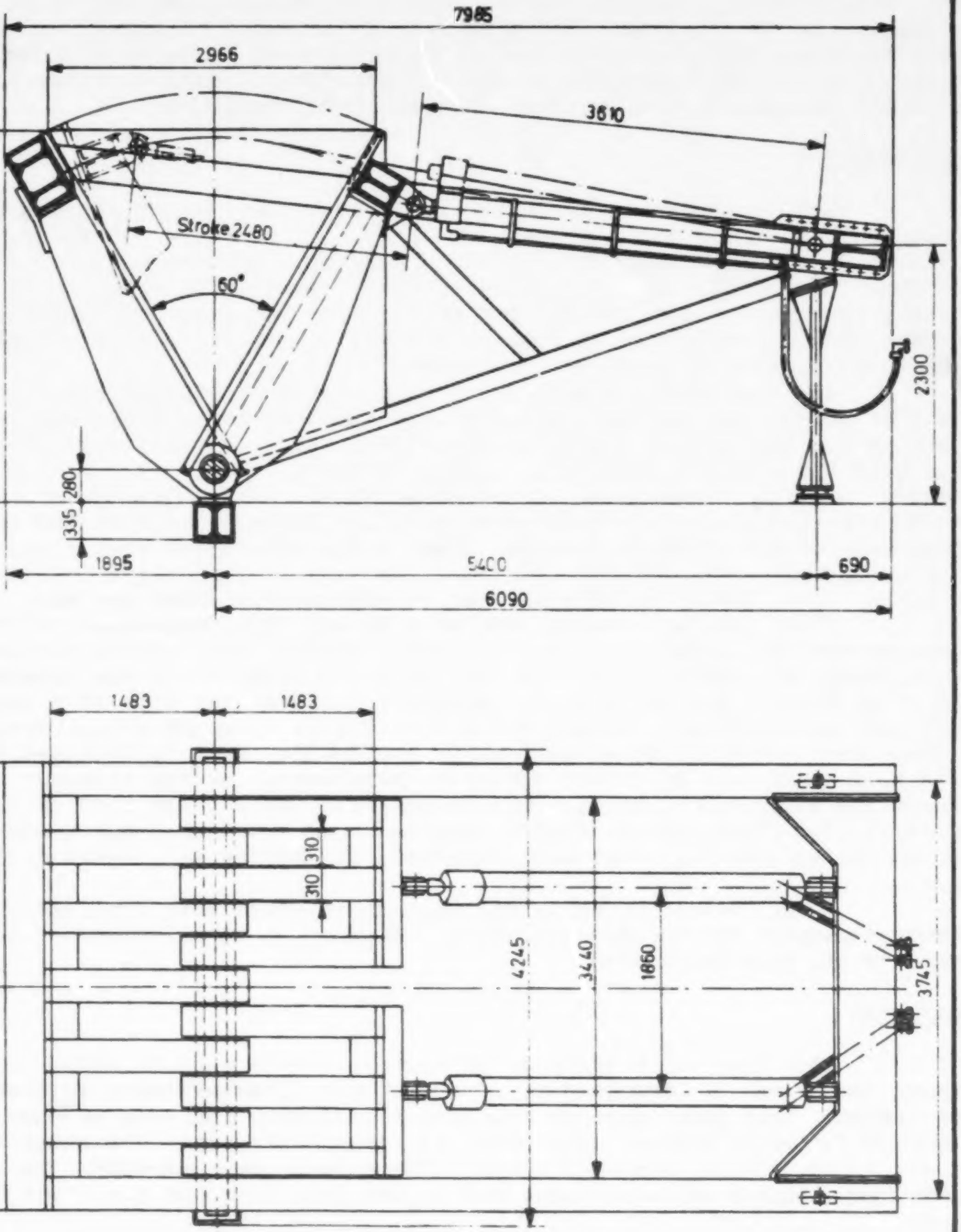
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FIGURE P-21. ELEVATION AND PLAN VIEWS OF VON ROLL SHEAR the hammers every 3 months, the receipt of bulky wastes was limited to a maximum size of one meter. The homeowner is required to break up any objects larger than one meter on a side or to send large metal objects directly to a scrap dealer. The shredder is now operated only occasionally to assure that its working parts are kept inoperable condition.

Duesseldorf

A 15 tonne/hr shear is available at one end of the pit area at Duesseldorf to cut up bulky wastes. See previous Figure P-1. Since May, 1973, a 45 tonne/hr shredder located in a separate building has been used to shred bulky wastes. When the scale operator observes bulky waste in a truck, he directs it to either the shredder or the shear. The standard refuse container in Duesseldorf takes up to 0.6 m (2 ft) pieces. Larger pieces must be cut or broken by the homeowner.

The Lindenmann shear is a hydraulically driven knife and bar machine usually operated 3 to 4 hours per day. At times of heavy use, the operator is assisted by a scale operator. The shear produces pieces about 0.6 m by 0.5 m (2 ft by 1.6 ft). Rubber tires are usually cut to 0.25 m square (0.8 ft). Shear load is indicated by the current input to the hydraulic-driven motor. Shear stroke can be manually adjusted by the operator. Operating time is recorded. Shear blades are turned over every 3 months and are replaced once per year. The ram of the shear is replaced every 10 years. The hydraulic seals must be replaced five times per year.

The Lindemann shredder was added in May, 1973. Duesseldorf is the headquarters for Lindemann. It is a horizontal-shaft, belt-driven machine which operates about 6 hours per day. No one is permitted in the shredder building during operation owing to explosion hazards. The size of pieces produced is relatively large--0.3 m by 0.5 m (1 ft by 1.6 ft)--although rubber tires may pass through essentially intact. The output is conveyed to the main plant pit by a belt conveyor. Maintenance on the shredder is minor. The management attributes this to the relatively large size of the product. The first set of shredder hammers lasted 4,000 hours during which 40,000 tonnes (44,000 tons) were shredded. The second set lasted 3,000 hours.

Much more difficulty has been experienced with the feed and output conveyors for the shredded refuse. The oil mist lubrication for the conveyor has been ineffective.

Wuppertal

When the scale operator at Wuppertal observes bulk refuse in a truck, the driver is instructed to deliver it to a Lindemann shear adjacent to the pit. This shear operates from 7:00 a.m. to 4:00 p.m. With no storage location for bulky wastes, trucks must, at times, wait until the shear is free. A new storage bunker is planned. There are 2 shear operators, one of whom does cleaning and maintenance work on the shear from 2:00 p.m. to 4:00 p.m.

The nominal capacity of the shear is 1 tonne or 20 m^3/hr or approximately 150 m^3/hr (200 yd^3/hr) of normal bulky refuse. From the shear, the cut refuse flows by gravity into the pit.

Paris-Issy-les-Moulineaux

Bulky wastes (stoves, bedsprings, etc.) are not normally sent to the Issy plant. The plant can accept almost any size material that can get into a traditional garbage truck. Industrial waste generators sign a contract where they agree not to deliver bulky liquid and other hazardous waste to the TIRU plants. Several times per year, special bulky waste collections are held.

However, if bulky wastes are taken to Issy, the scale operator can order the driver to offload onto an open area and thus the oversized pieces never enter the pit. The Martin hopper, feed chutes, grate, and ash handling systems can, however, accomodate very large objects, but the eventual bottleneck is often the ash discharger.

One amazing example was a fully assembled Fenwick forklift truck that was found inside the furnace on the grate. Because it could not pass through the ash handling system, it was removed after first being torch cut.

Also, other undesirable objects do enter the pit and may require the following actions:

(1) If in the pit, pull large objects up to small platform next to and at the level of the hopper. Using welding torch cut the object into smaller pieces. Drop pieces into the hopper for normal processing.
(2) Using the crane bucket, use hooks and rope to pull the bucket back to the truck tipping door.
(3) Use long rakes and hooks for dislodging in the hot furnace.
(4) Use shorter rakes and hooks at the end of the ash discharger.
(5) Assess penalties against the waste generator.
(6) If the waste generator continues to send undesirable material to the plant, cancel his disposal privilege for 2-3 months.

Unfortunately, the pit area is not designed for a crane to simply pick up the bulky or hazardous object for setting aside on the floor or into a truck container. Martin engineers recommended that such provisions be made at future plants.

Zurich-Hagenholz

A scissor shear, manufactured by Von Roll operates from 6 a.m. to 8 p.m. five days per week at Hagenholz. This unit operated 2,931 hours in 1974 and 2,809 hours in 1976. Normally this type of shear does not need an operator in residence because it is in motion all the time. It can process one to ten tonnes per hour.

In contrast to many other size reduction methods, the Von Roll Hagenholz unit has been almost 100 percent reliable. Routine inspections are conducted and repairs made three (3) times per year and the expected life is at least 20 years.

The knives are completely changed every 16 months. But during that period, the edges are rotated four (4) times, i.e., once every four (4) months.

Once per week, the knives are cleaned. Bed springs and large tires can be a problem and may need to be extracted with a long hook.

Originally, the shear was not strong enough and was later reinforced. There will be no shear at the new Josefstrasse plant because the chute will be larger, i.e. 1.5 x 6 m (5 x 20 feet).

Hamburg

The Stellinger-Moor plant does not have a shear or shredder because the management feels that the bulky waste problem is so minor that capital and maintenance costs are unjustified.

The Hague

The original plant design for The Hague included a 15 tonne/hr Von Roll shear. This shear received bulky waste form the small bunker which receives primarily bulky waste from private haulers. However, owing the light construction of this early shear design, much maintenance was required. Also, some explosions were experienced within the shear. Accordingly, in 1970 the use of the shear was discontinued and the crane operators are instructed to try to smash bulky objects in the bunker by dropping the crane bucket on them. Also, there is a holding pit which is positioned to receive either sheared material or smaller bulk refuse that can be by-passed over the shear. From that pit, the operators of the main bunker cranes can lift refuse directly to the furnace hoppers or it can be deposited in the main bunker for mixing with conventional refuse. This complex arrangement requires good judgement and skill on the part of the crane operators to assure a well-mixed and reasonably sized supply of refuse to the four furnaces.

Gothenburg

When the crane operator at Gothenburg's Savenas plant observes oversize waste being delivered, he can lift it to one of two Von Roll Model 13/310 shears situated between two of the furnace feed hoppers to have it cut to smaller size. The cut pieces fall from the shears into the refuse pit. The rated shear capacity is 120 tonnes/hr each.

Uppsala

At Uppsala a Von Roll scissors type shear, operated by the crane operator, has the capacity to reduce 4m (13 ft) bulky refuse to 0.3 m (1 ft) pieces.

Horsens

Bulky waste is now sent directly to the Horsens landfill which has a shredder. However, plans have been made to install a shear estimated to cost 500,000 D.Kr. ($83,333). An alternate being considered is a double screw size reduction device licensed by Norba and built by Volund. One such installation at Horsholm is said to have provided good service for about 10 years.

Copenhagen-Amager and West Plants

The Amager plant has no provision for bulky waste because the adjacent transfer station screens out all bulky items. But at the West plant the scale operator directs drivers with bulky wastes to either of the two Lindenmann "Lomal 10" shears. The second shear was added in 1975. About 40-50 percent of the refuse input is processed through the shears. Previously, bicycles, tubs, furniture, etc. had been jamming in the refuse hopper, chute, and ash discharge operations. The current rule to drivers is that all garbage collection trucks and transfer truck-trailers disgorge directly into the refuse pit. Equally as firm is the rule that all other trucks (especially detachable container loads) must discharge to the Lindeman shears.

The shears are adjacent to the pits. They are rated at 80 m^3/hr. Operation is intermittent and only on the day shift when the operator is present. The drive is hydraulic.

The maintenance record has been excellent. Blades are replaced usually after one or two years. With the rule that all miscellaneous truck loads must go to the shear, several problems have arisen. For example the hear is sometimes difficult to operate when overloaded with small-sized and wet refuse such as a truck load of grass clippings.

These shears cost 2.5 to 3.5 million D.Kr. ($450,000 to 600,000) each.

Hoppers and Feeders

An integral feature of the pit-and-crane system is that each furnace receives its waste from a hopper and chute which are fed intermittently by the crane bucket. This intermittent batch feeding is converted to nearly uniform flow to the furnace-grate by 2 factors:

1. Short-term storage capacity of the hopper and chute
2. Action of a reciprocating or vibrating feeder which moves the refuse from the chute to the grate.

Figure P-22 shows a diagram of the feeder arrangement at Zurich-Hagenholz. The feeder serves a multiple purpose. In addition to supplying fuel to the furnace its action in moving packed refuse away from the bottom of the chute permits the crane operator to keep the chute packed full. This packed mass served to prevent burn-back from the furnace into the chute and hopper.

At times the crane operator may be so busy with multiple problems of receipts, mixing and charging that some chutes may inadvertently become emptied. If so, burn-back into the feed chute can occur. Accordingly many chutes are equipped with gates or dampers that can be closed to prevent flames from flowing upward through the chute and hopper. Some newer chutes are equipped with radioactive level indicators which provide indication in the control room and crane pulpit when the refuse level is low.

Because of the potential for burn-back causing overheating of the feed chute, some chutes are water cooled or refractory lined.

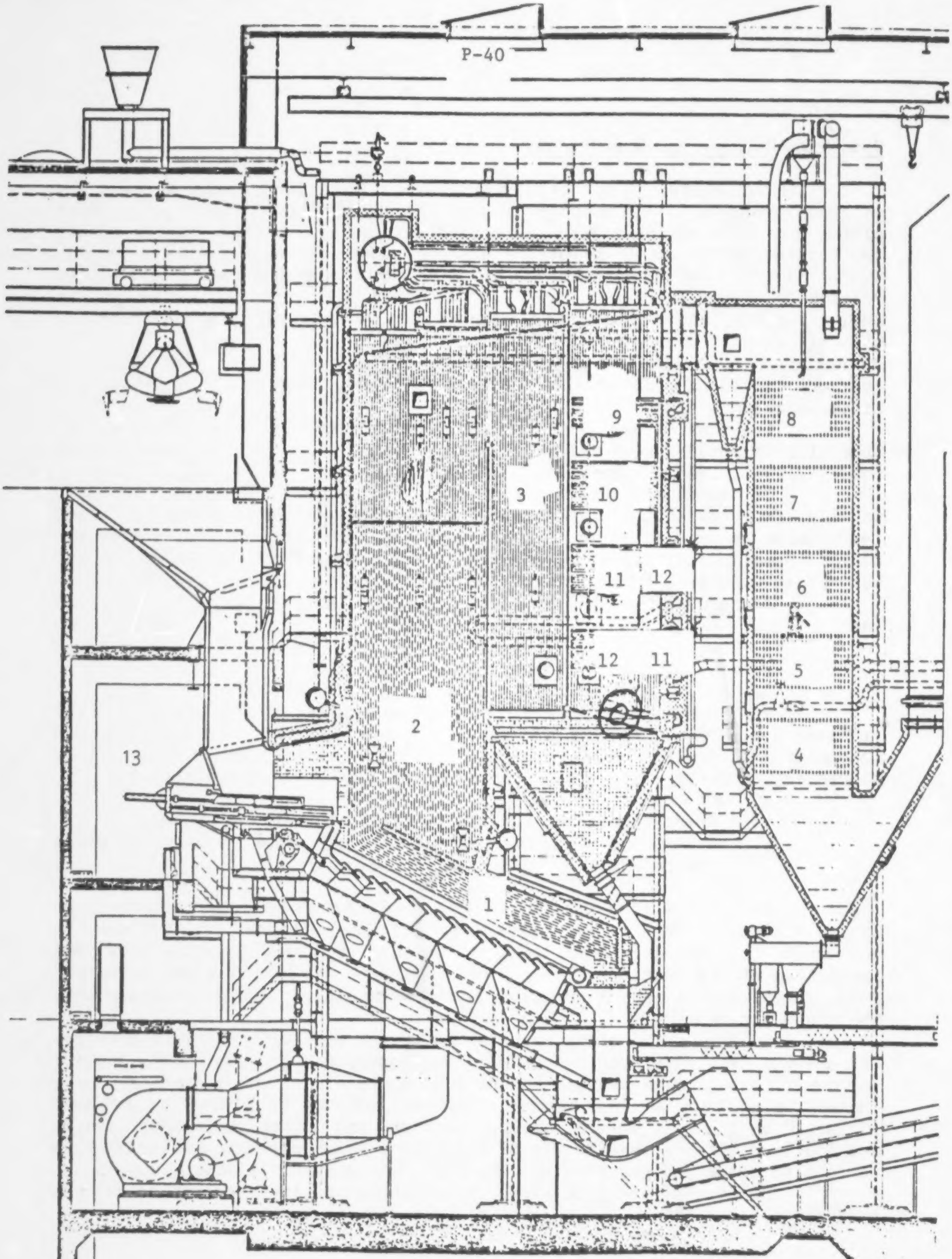
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FIGURE P-22. FURNACE/BOILER CROSS-SECTIONAL VIEW OF THE ZURICH: HAGENHOLZ UNIT #3
13 Martin's Double Feeder

Werdenberg-Liechtenstein

At the small Werdenberg plant, the single furnace hopper is 4m by 4m (13.1 ft by 13.1 ft) and the feed chute is 2.5m by 1.5m (8.2ft by 4.9 ft). The chute is insulated but uncooled. The lower portion of the chute near the furnace is low alloy steel to reduce deterioration from high temperature. An insulated cover can be placed over the hopper top to stop burnback, if it occurs, by preventing air or gas flow. (See the previous Figure P-7)

The single-level, ram-type, inclined feeder is hydraulically driven by a Vickers drive. It feeds intermittently about 12 strokes per hour which is about half the frequency of the reciprocating grate sections. The feed is manually controlled from the control room. A spare hydraulic drive is available. No repairs have been needed in 3 years.

Baden-Brugg

At Baden-Brugg, with two 120 tonne per day furnaces, the top of each furnace hopper is 4m (13.1 ft) square and the feed chute is 2.5m by 1.5m (8.2 ft by 4.9 ft). The chute is not cooled nor insulated. If burnback into the hopper occurs it can be stopped by means of hinged insulated cover placed over the hopper. When large objects jam the chutes a heavy wood ram held by the crane grab is used to force the object downward.

A single level, hydraulically-driven ram feeder made by Hydro feeds the refuse inward every 1.5 minutes. The length of stroke is 600mm (2 ft). The speed of the motion is fixed. If something prevents the ram from withdrawing from the furnace an alarm sounds. Reliability has been essentially 100 percent. There is no feeder redundancy. After 7 years operation the cyclinder on the drive has recently been replaced. The piston guide is lubricated once per month.

Initially the feeder piston seal leaked. That defect was corrected. The feeder plate was changed from cast iron to steel because early in the operation, heavy objects falling from the feed chute broke the feeder plate.

The Baden-Brugg furances begin with a water cooled arch connecting the feed chute exit to the top of the furnace entrance. This minimizes burnback. (See Figure 24)

Duesseldorf

Figure P-23 shows the original hopper, chute and feeder at Duesseldorf. Some modification of the original 5 m by 5 m (16.3 ft by 16.3 ft) hoppers has been required to prevent bridging in the pyramidal hopper. The remedy was to raise one side of the sloping hopper wall so that less material could crowd downward into the feed chute. This crowding caused the bridging. Also, the feed chute, 3 m by 1.8 m (10 ft by 5.9 ft), was changed,tapered outward from top to bottom at the rate of 150 mm (5.9 in) in 5 m (16.3 ft) to relieve the tendency to jam in the chute. In 1975 the height of the opening where the refuse is pushed from the bottom of the chute into the furnace, was reduced somewhat on three of the boilers to prevent burnback. Also water cooling was added to the lower 2.5 m (8 ft) on some of the feed chutes. On those chutes, which are not water cooled,

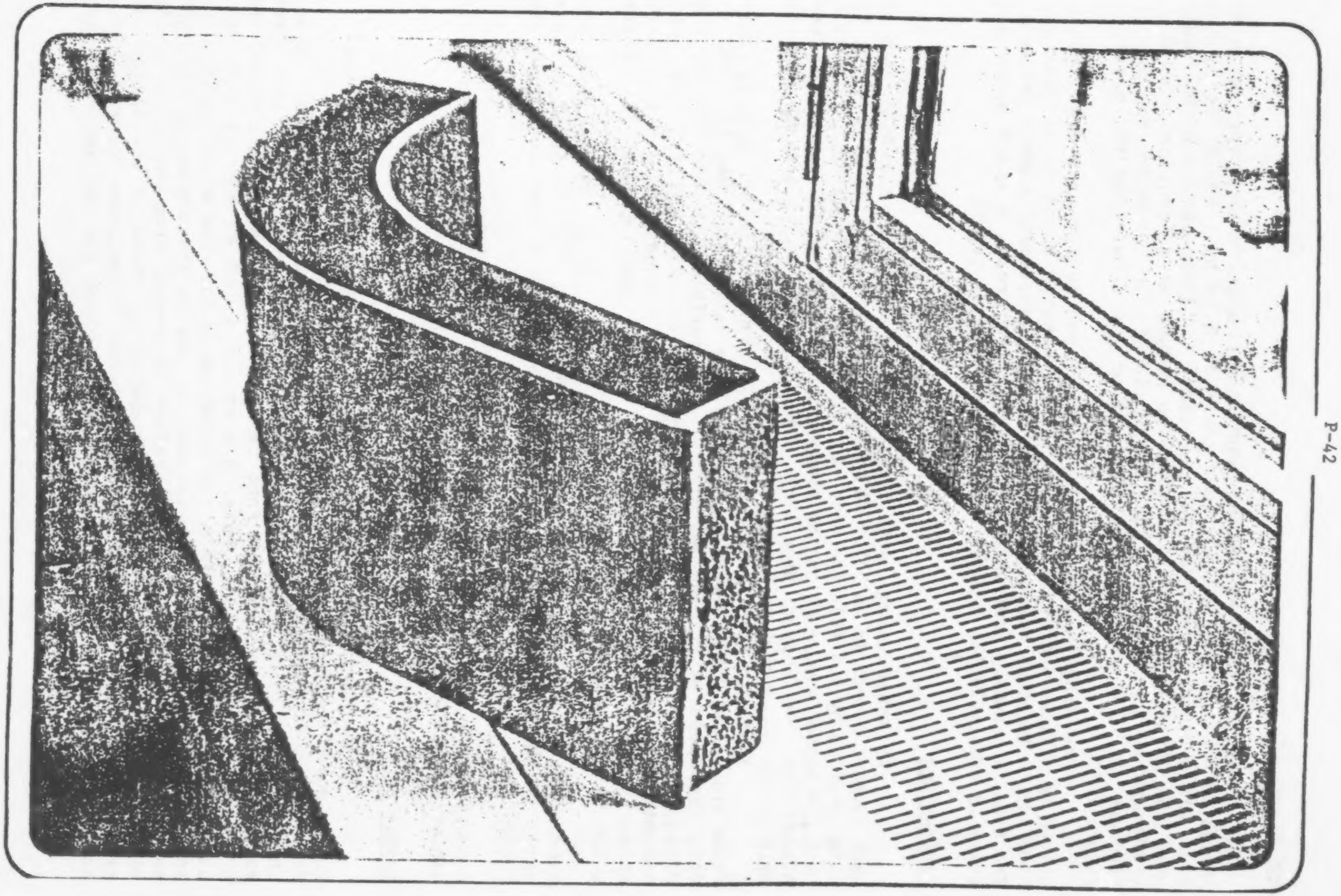


FIGURE P-23. WATER COOLED ARCH CONNECTING FEED CHUTE TO COMBUSTION CHAMBER AT BADEN-BRUGG (Battelle Photograph)

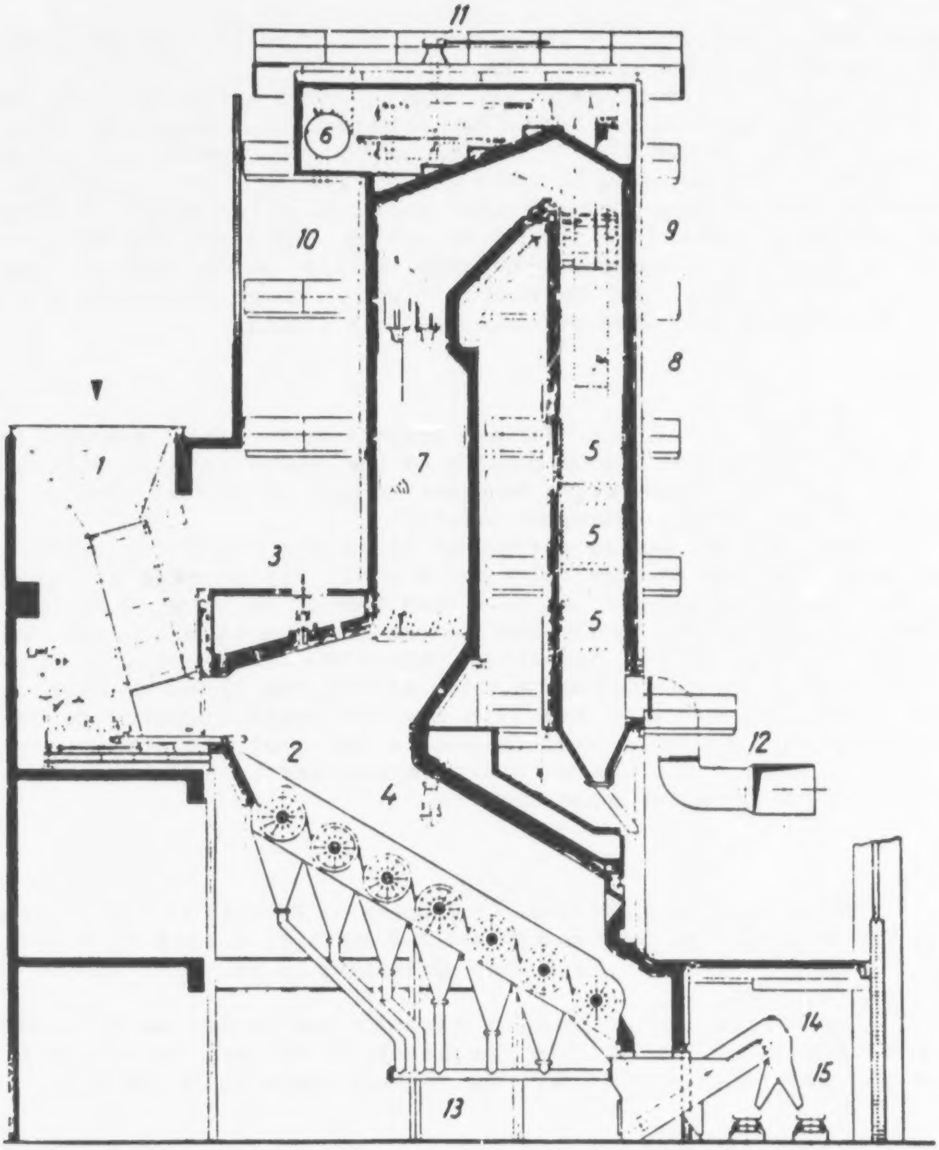


FIGURE P-24. CROSS SECTION OF ONE OF BOILERS NO. 1-4 (Courtesy of Stadtreinungs und Fuhramt Duesseldorf)

1. Refuse hopper
2. Refuse feeder and roller grate "system Duesseldorf"
3. Ignition burner
4. Heavy oil burner (both sides)
5. Economizer
6. Steam drum
7. Radiant water-tube-wall boiler
8. Boiler convection section
9. First and second stage superheater
10. High-temperature superheater
11. Steam discharge
12. Exhaust gas duct to electrostatic precipitator
13. Ash siftings removal
14. Wet residue conveyor
15. Residue removal to processing plant

burnback during shutdown is prevented by use of guillotine doors covering the opening between furnace and chute.

Four of the reciprocating refuse feeders are mechanically driven and one drive is hydraulic. They feed horizontally under the automatic control of boiler steam flow but are limited by furnace temperature and excess oxygen. If temperature is too high or oxygen is too low, feed rate is reduced. The reciprocating feeder plate is water cooled. The forward feeding stroke is faster than the return stroke. Operators prefer the four mechanically driven feeders because they require less maintenance than the hydraulic drive. Also, any hydraulic fluid leakage constitutes a fire hazard. The feeders used were developed at this plant.

Wuppertal

The top of the four furnace hoppers at Wuppertal are each 5 by 5 (16.3 by 16.3 ft) square. Water cooling of the chutes is available but is used only when the temperature becomes to high. A lifting type of damper can close off the chute if burnback occurs.

Each stoker has an automatic hydraulic ram-driven feeder which can be controlled from the control room. Normally it strokes 15 times per hour. The length of stroke can be varied from 20 to 50 cm (5 to 12 in) by adjustment at the feeder. So far the feeders have had no problems. On some occasions, during initial operation, there was back-burning in the chute caused by loosely packed wood waste which allowed the flames to move upward in the chute. The solution has been for the crane operator to mix the refuse and to charge the hoppers in such a way that the chutes are kept packed full. Repeatedly, here it was emphasized that the most important worker in the plant is the crane operator.

Krefeld

The top opening of the two hoppers at Krefeld is 4.5 m (14.8 ft) square. The water-cooled feed chute is 1.8 m by 2.85 m (5.9 by 9.4 ft). A hydraulically operated damper in the upper part of the chute can be closed in case of burnback.

The stroke frequency of a hydraulic ram feeder can be controlled from the main control room. The frequency of the ram can be adjusted between five and fifty strokes per hour. Normal speed is 15 per hour.

Paris: Issy-les-Moulineaux

The hopper opening at Issy is 6.25 m (20.67 feet) by 9.8 m (32.34 feet). The hopper tapers off to the chute having dimensions of 1.438 m (4.7 feet) by 6.25 m (20.5 feet). Normally, the hopper is kept empty while the feed chute is full. The chute has a water cooled jacket. There is also a horizontal water-cooled cut off gate to minimize burnback. Finally, there is a water-cooled cut off gate to minimize burnback. Finally, there is a water-cooled arch connecting the top of the feed opening to the combustion chamber.

Not typical of most Martin plants, Issy plant experiences frequent burnback during startup -- about 90 percent of the time. Burnback n shutdown is not quite as frequent. In Martin's newer Zurich plant, steam nozzles at the rear and bottom of the chute propel the refuse out onto the grate, thus minimizing burnback while the chute is being cleared or filled.

The chute has one access door for maintenance access during outage of the incinerator.

Of the four Issy furnace feeding systems, one is hydraulic 15 bar (220 psia) and three are electro-mechanically driven. Plant officials value the systems as about equal. Martin officials admitted their initial skepticism regarding hydraulic feeders as proposed by TIRU. However, Martin now normally recommends the hydraulic feeders. A key feature is that the hydraulic system responds better to a jamming object without breaking. A mechanical system will more easily break. The main problem with the hydraulic system is oil loss with accompanying potential fire hazard.

Each of the three runs per furnace has two feeder mechanisms; an upper and a lower ram or pusher. The furnace feeder total width is 6.3 m (20.67 feet),i.e., 3 x 2.10 m. The depth is 4 m (13.2 feet). The cross section of the fuel entry in to the furnace is 8.82 m^2 (95 ft^2) having dimensions of 6.3 x 1.4 m (20.67 x 4.6 feet).

Each pusher is provided at its front end with heat-resisting chromium steel alloy bars 12 mm thick at its rear end with a 10 mm thick steel plate, which is reinforced to withstand the impact of refuse falling from the hopper. Each pusher is supported at its front end by sliding noses, and at its rear end by roller bearings on each side and guided by a vertical roller bearing. Each pusher is operated by a hydraulic cylinder.

The control of the feeding device is over a range of more than 1 to 10. The control equipment is mounted in the hydraulic control cabinet together with the control equipment of the grate. The feeder control is of the auto-manual type where the manual operation may be controlled locally or from the control room.

In some recent systems the refuse level within the chute at the minimum allowable level can be measured by a radioactive device and indicated in the crane operating cab and in the main control room.

Hamburg

Each hopper openig at Stellinger-Moor is 5.9 m (19.3 ft) by 6.3m (20.7 ft). The hopper tapers to the chute which is 1.5 m (4.9 ft) by 4.9 m (16 ft). Normally, the hopper is kept empty while the feed chute is full. The chute has a watercooled jacket to reduce the effect of burnback.

As the average refuse heating value has risen, there have been more burnback instances as ignition occurs closer to the chute. To reduce the ignitability of the refuse, water was sprayed directly onto the refuse in the hopper. Burnback was substantially reduced to once every week or two.

Now most of the burnback comes from large voids in the chute due to a bulky desk or cabinet. Also, an iron bar may jam the feeder, causing normal refuse to burn but preventing new refuse from entering the combustion chamber. When asked if a shredder might alleviate the problem of chute-feeder jamming, the response was that "two million DM ($800,000) was too high a price to pay for solving such a minor problem". Repairs to a shredder or a shear might be even more expensive than repairs for occasional shutdowns of the feeder.

Each of the two grate runs per furnace has two feeder mechanisms: an upper and a lower ram or pusher. The furnace feeder total width is 4.2 m (13.8 ft), ie., 2 x 2.10 m. The depth is 4 m (13.1 feet). The cross section of the fuel entry into the furnace is 8.82 m^2 (94.90 ft^2) having dimensions of 6.3 x 1.4 m (20.67 x 4.6 feet).

Each pusher is provided at its front end with heat-resisting chromium steel alloy bars 12 mm thick and at its rear end with a 10 mm thick steel plate, which is reinforced to withstand the impact of refuse falling from the hopper. Each pusher is supported at its front end by sliding noses, and at its rear end by roller bearings on each side and guided by a vertical roller bearing. Each pusher is operated by a hydraulic cylinder.

The control of the feeding device is over a range of more than 1 to 10. The furnace feed rate can thus be set at between 20 and 40 tonnes (22 and 44 tons) per hour. Martin's analog computer controls exact feed rate based on instantaneous temperature readings taken at the top of the first pass.

There have been some hydrualic feed system problems with sticking valves at the pumping station. Nevertheless, the plant operators emphasized their preference for "hydraulic only" systems over mechanical drive systems. As one operator stated, "we may have minor problems with the hydraulics, but a mechanical system would actually break if jammed".

In future systems, Martin often recommends a system where the refuse level within the chute at the minimum allowable level can be indicated by means of a radioactive device communicating to the crane operating cab and the main control room.

Zurich

At the Hagenholz plant, Unit No. 3, the hopper dimensions are 5.517 m (18 ft) by 7.056 m (23 ft).

The hopper tapers to the feed chute that is 1.5 m (4.9 ft) by 5,486 m (18 ft). The chute is surrounded by a water jacket.

Burnback has only occured once in four (4) years in Martin's #3 unit. While not certain, operators suspect that superheater tubes might have become plugged to a point where the furnace became positive pressurized. Another reason might be that the I.D. fan was not functioning properly. For whatever reason, pressure likely built up and fire eventually backed up the chute.

An explanation was made for the excessive burnback experience at Paris: Issy - les - Moulineau. Issy has a very high chute. As a result, an induced draft pulls the flame back up the chute in 90 percent of all start-ups. Hagenholz is fortunate to have a stubby chute and wide enough spaces between boiler tubes.

Unit #3 has three (3) grate runs. Each run has upper and lower Martin feeders with the following specifications. Stoke frequency is a function of steam temperature, steam pressure, and temperature entering the electrostatic precipitator. The feeder characteristics are:

	Upper	Lower
Stroke (maximum)	600 mm	1000 mm
Stroke (normal)	180 mm	300 mm
Frequency (strokes/minute)	2 to 5	2 to 5

The feeders are hydraulically driven. Preventive maintenance helps achieve reliability of almost 100 percent. On one occasion, a waste container of acetone spilled into the chute, leaked out of the chute and onto the rubber hydraulic lines. The acetone entering the furnace caught fire which transmitted to the rubber tubes outside the chute. The tubes were replaced with flexible steel hoses.

The feeders are controlled by the Martin "black box".

Zurich officials are pleased with the hopper and feeder performance and Martin will use the same design at the new Josefstrasse.

The Hague

Figure P-13 shows a cross-section of boiler/furnaces 1-3 which were built in 1967. Each of the four furnace hoppers has a top opening of 5 by 3.7 m (16.4 by 12.1 ft). Immediately beneath the hopper is a large vibrating feeder which feeds into a water-cooled chute about 3.4 by 1 m (11 by 3.3 ft). The feeder, made by Schenck of Darmstad, West Germany, is vibrated by rotating eccentric weights automatically controlled by a radioactive chute-level indicator made by endress and Hauser. The radio-active source is Cesium 37 with an intensity of 75 milliroentgens.

Burnback in the chute never occurs on start-up or shut-down, only if the chute jams, preventing full flow or refuse. A flap damper can be used to seal off the top of the chute in case of burnback. Jamming in a hopper can be released by the force of a railroad tie dropped in by the crane bucket. The vibrating feeders have been trouble-free for nearly ten years. It is expected that the steel floor-plate of the feeders will need replacement after about 12 years of service.

Dieppe and Deauville

The hoppers at both of these plants are similar, 2 m by 4 m (6.5 by 13 ft) at top and at the base of the chute, the dimensions are 1.6 m by 1.2 m (5.2 by 4 ft), with the juncture between hopper and chute sealed by a flap damper to prevent burnback. This method of feeding and sealing is impractical for much larger plants were Von Roll uses a vibrating feeder to feed from the chute to the furnace. At both plants, the chute is water jacketed but a thermocouple in the jacket at Deauville indicates that water flow to the jacket for cooling is seldom needed. Some wet-type corrosion was visible on the jackets.

A sloping reciprocating type of feeder in the furnace feeds the main burning grate. There is no combuston air supplied to the feeder.

Gothenburg

The top of the three furnace feed hoppers is 3.5 by 2.4 m (11.5 by 8.1 ft) each. At the hopper bottom is a sloping vibrating table built by Schenk and having an amplitude of 8 mm (0.3 in). The feeders are controlled by radioactive level indicators in the water-cooled feed chutes. The indicators use Cesium 136 and were made by Endres and Hauser of Lorrach, Germany.

The vibrating feeder has been satisfactory. The chief engineer pointed out that the use of a vibrating feeder to feed the vertical chute 1.2 by 3.4 m (4 by 11 ft) requires about a 3 m (10 ft) height of refuse in the chute to assure a tight air seal and avoid burnbacks in the chute. If a hydraulic ram feeder was used just above the grate to maintain a seal, most of the 10-meter chute height could be eliminated, thus reducing overall building height by about 10 meters. However, the tall chute does provide a simple, easily managed seal that has effectively minimized burnback.

Uppsala

Figure P-25 shows Furnace No. 4 the Brunn and Sorensen installation at Uppsala. The vertical outwardly tapered steel chute feeds directly onto the sloping grate without assistance by any feed mechanism except the feeding action of the grate itself. For the first three furnaces built by Kockum-Landsverk (not a part of Volund), the feed chutes are not provided with dampers to control burnback. Instead, the height of the gravity-packed refuse in the chute is depended upon as a seal. However, with furnace No. 4 installed in 1970, the confinement of the existing roof structure and the height of the top of the Brunn and Sorensen grate imposed an upper limit on the length of the feed chute. Thus, to control burnback in the chute, a double flap damper was installed. The operators have had no problem with burnback.

Figure P-26 shows a view into the empty hopper where a thin line of flame is visible between the mating halves of the flap damper.

Horsens

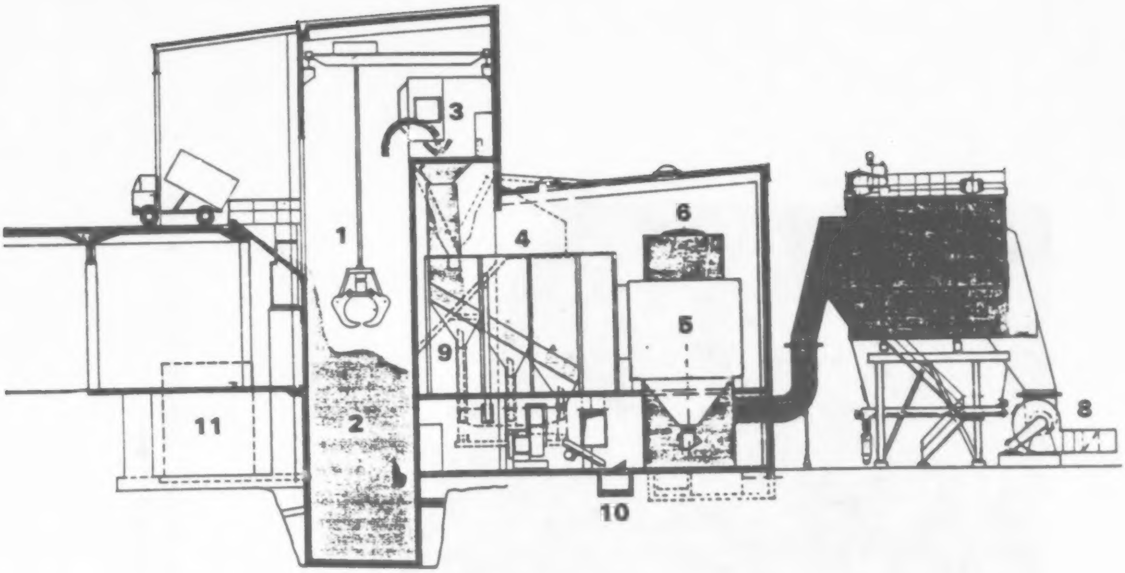
The top opening of the single hopper at Horsens is 4.2 by 4.8 m (13.8 by 15.7 ft), and it is 2.1 m high (6.8 ft). The refuse flows by gravity from the hopper into a refractory-lined feed chute 1.11 m high (3.6 ft) and 1 by 1.6 m (3.28 by 5.2 ft) at the top, tapering out to 1.6 by 2 m (5.2 by 6.5 ft) at the bottom. Burnback can be arrested by the cast iron flap damper in the chute.

The poured refractory lining of the chute is 50 mm (2 in) thick, held in place by welding anchor rods.

At the bottom of the chute, the refuse is fed on to the sloping grate by a similarly sloping hydraulic feeder designed by Bruun and Sorensen and built by Monsund. The feed ram has a maximum stroke of 2.5 m (8.2 ft) and a capacity of 5 tonnes/hour. Variable feed is provided by timer which can be adjusted by the operator from 0 to 1 stroke/minute. The only problem with the feeder has been oil leakage.

Copenhagen: Amager and West

At the Amager and West plants the hopper dimensions at the top are 6 m (19.7 ft) by 6 m (19.7 ft). At the hopper bottom, the dimensions are 2.3 m (7.5 ft) by 1.15 m (3.8 ft). Its height is 6 m (19.7 ft). The



1. Crane and Bucket
2. Refuse Bunker
3. Crane Operator's Station
4. Furnace
5. Afterburner Chamber
6. Steam Boiler
7. Electrostatic Precipitator
8. Induced Draft Fan
9. Primary Air Zones
10. Residue Conveyor
11. Waste Oil Tank

FIGURE P-25. ARRANGEMENT OF UPPSALA PLANT
(Courtesy Bruun and Sorenson)

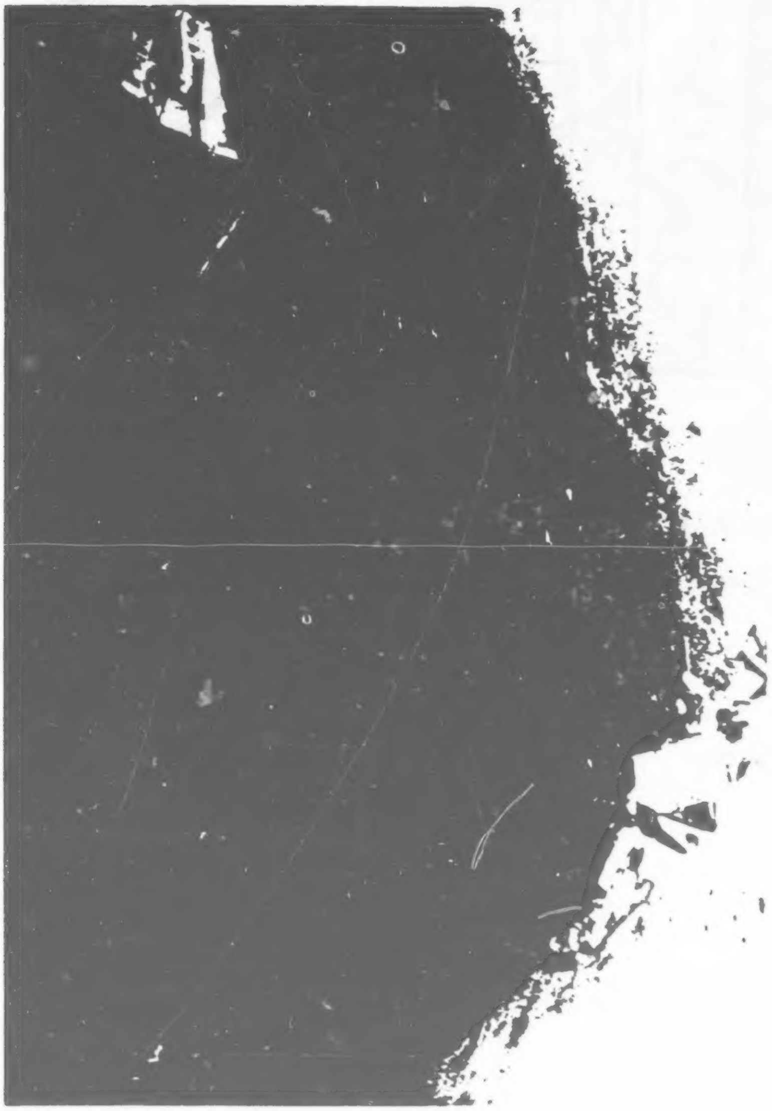


FIGURE P-26. EMPTY FEED HOPPER SHOWING LINE OF FLAME BENEATH DOUBLE FLAP DOORS AT UPPSALA (Battelle Photograph) walls are made from 8 mm (0.3 in) carbon steel. Sometimes Volund installs a concrete hopper instead of steel. Concrete is cheaper and reduces noise.

The filling chute has a slightly larger width dimension than the hopper: 2.7 m (8.9 ft) by 1.15 m (3.8 ft). It too is made of 8 mm (0.3 in) steel.

To prevent burnback a swivel gate or damper is located in the chute. It is opened when refuse falls on it and closed when no refuse is above it. The damper's dimensions are 2.58 m (8.5 ft) by 1.26 m (4.1 ft) and is 10 mm (0.39 in) thick.

Amager and Volund officials do not believe that a water-cooled chute is necessary. Volund typically installs chutes with only refractory lining. Except for flowing material, the hopper should always be empty. There should be no refuse above this kind of damper to interfere with its closing. With proper crane operator training and performance, burnback can be minimized. Officials believe that water cooled jackets, besides being unnecessary, increase costs of operation and maintenance.

Originally at West the damper (swivel gate) on Units 1, 2, and 3 was located 2 m (6 feet) below the hopper/chute interface. Severe burnback and metal warpage resulted. The 12 mm (0.5 inch) support ribs warped in addition to the walls themselves. Figure P-27 shows the effects. The plant successfully reduced serious burnback by raising the damper level to only 0.5 m (1.5 ft) below the hopper/chute interface. West Units 1-3 are equipped with special pneumatic air hammers that can be used to dislodge jammed feed hoppers or chutes.

In planning Unit 4 (which began operation five years later), the designers also specified that refractory brick should be extended internally up to the hopper/chute interface. Even with this, there has been some burnback.

Another cause of burnback in the early years was that the crane operators would put too much refuse in. Except for flowing material, the hopper should always be empty. There should be no refuse above this kind of damper to interfere with its closing. Persuasion and practice rectified this problem. Unless radioactive monitoring is used, the crane operator should view the hopper/chute interface if designed as West is designed.

FIGURE P-27. WARPED FEED CHUTE AT COPENHAGEN: WEST

GRATES AND PRIMARY AIR

General Comments

The grates used in the early stages of mass burning of refuse were adapted from coal burning practices, the principal change being to provide much more fuel-bed agitation. This was needed because refuse is so heterogeneous that discontinuities and gaps are always present and new ones can form as the refuse burns. Agitation of the bed is the means used to shuffle, tumble, or resettle the burning fuel so as to fill the gaps and make it more uniform for better distribution of primary air and of burning.

Three basic grate systems are used as shown in Figure Q-1. There are many other variations of these three types.

This report concentrates on European refuse burning to energy systems. All systems visited have been mass-burning grate systems. To our knowledge there was only one system in Europe (Birmingham, England) burning refuse in suspension --- in contrast to U.S. developments. For the benefit of American decision makers, both mass-burning and suspension systems are listed in Table Q-1. This table includes a listing of independently developed refuse burning systems, their home country and their American representative "Refuse burning" refers to "combustion" or incineration" where combustion products after a few seconds are H_2O, CO_2, SO_2, etc. There is no attempt to present manufacturers of pyrolysis or other developmental resource recovery processes, i.e. this is not a full list of resource recovery manufacturers. Also excluded are the many manufacturers of small modular package incinerator-heat exchangers. The table includes present and past manufacturers with heat recovery.

Manufacturers of only incinerators (without boilers to cool combustion gases prior to gas cleaning) are not included in the listing.

Grate Functions

The three primary functions of grates are:

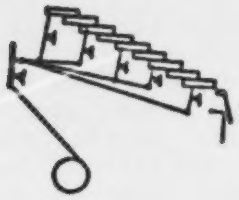
- Support the burning refuse
- Move and agitate the burning refuse
- Distribute the primary air.

There is a wide range of differing design philosophies aimed at achieving these three functions. While all the grates observed do accomplish these primary functions, they do so at varying levels of grate maintenance required and with varying success in achieving uniform combustion.

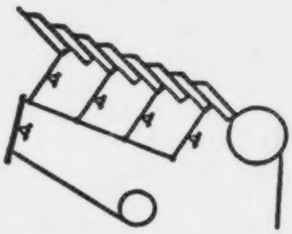
Table Q-2 compares the grate design characteristics for the plants visited. The grate burning capacities range from 24.6 down to 3.33 tonnes (27 to 3.7 tons) per hour, a unit size range of 7.4 to 1. And the burning rates range from 560 down to 175 kg/m^2/hr (114.6 to 35.8 lb/ft^2/hr), a range in rates of 3.2 to 1.

If all other factors are equal, the higher the grate burning rate, the more effective and efficient the grate will be. However, the effect of the grate on the combustion in the boiler furnace is of critical importance to boiler-furnace life and efficiency. It appears that one popular design philosophy is to use moderate burning rates and large boiler furnaces to provide reasonable heat recovery efficiency while minimizing maintenance.

Reciprocating Grate



Reverse Acting Grate



Roller Grate

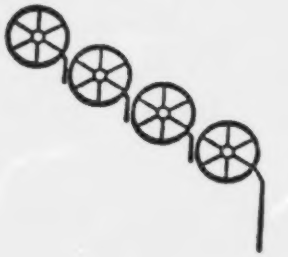


FIGURE Q-1. BASIC TYPES OF GRATES FOR MASS BURNING OF REFUSE. THERE ARE AVAILABLE MANY VARIATIONS OF THESE BASIC TYPES (FROM EBERHARDT-PROCEEDINGS 1966 NATIONAL INCINERATOR CONFERENCE, ASME, NEW YORK, p 124-143)

TABLE Q-1. REFUSE BURNING MANUFACTURERS AND REPRESENTATIVES (Traveling Grate and Suspension Firing)

International Technology	Country	Representative in the U.S.A.
Alberti-Fonsar	Italy (Milan)	Widmer & Ernst (Swiss Co.)
Babcock Wilcox (BW)	U.S.A. (North Canton, Ohio)	Babcock Wilcox
Bruun & Sorensen	Denmark (Aarhus)	looking for repre.
Carbonisation Enterprise et Ceramique (CEC)	France	
Claudius Peters	West Germany (Hamburg)	
Combustion Engineering (CE)	U.S.A. (Windsor, Conn.)	Combustion Engineering
De Bartolomeus	Italy (Milan)	
Destructor	Sweden	
Detroit Stoker	U.S.A. (Monroe, Mich.)	Detroit Stoker
Dominion Bridge	Canada	
Esslingen	West Germany	
Flynn & Emrich	U.S.A. (Baltimore, Md.)	Flynn & Emrich
Foster Wheeler	U.S.A. (Livingston, N.J.)	Foster Wheeler
Heenan	United Kingdom	
K Z K		
Kunstler Koch	Switzerland (Zurich)	Widmer & Ernst
Keller-Peukert	West Germany (Leverkeusen)	Grumman Ecosystems
Kochum-Landsverk	West Germany	
Kohlenscheidungs-Gesellschaft(KSG)	West Germany	
Kraus-Maffei	West Germany	
Lambian-SHG	West Germany (Kassel Bettenhausen)	
Lokomo	Finland	
Lurgi	West Germany (Frankfort)	
Martin	West Germany (Munich)	Universal Oil Products
Nichols	U.S.A.	Nichols Research & Engineering
Plibrico	U.S.A. (Worcester, Mass.)	Plibrico
Riley Stoker	U.S.A. (Chicago, Il.)	Riley Stoker
Stein	France	
Steinmueller	West Germany (Hamburg)	Widmer & Ernst (Swiss Co.)
Takuma	Japan (Osaka)	Inactive representative in CA.
Venien	France	
Vereinigte Kesselwerke (VKW)	West Germany (Duesseldorf)	Grumman Ecosystems (total system)
Volund	Denmark (Copenhagen)	
Von Roll	Switzerland (Zurich)	Wheelabrator - Frye
Widmer & Ernst	Switzerland (Wettingen)	Widmer & Ernst
Zurn Industries	U.S.A. (Erie, Pa.)	Zurn Industries

NOTE:
1. The above systems are combuston oriented.
2. Small modular package incinerator - heat exchanger manufacturers are not included.
3. Pyrolysis and other developmental resource recovery systems are not included.
4. The above systems have been installed with energy recovery.

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* International Incinerators, Inc. of Atlanta [illegible] the license until the mid 1970's when it expired. As of 1978, Waste Management [illegible] as assumed the license.

TABLE Q-2. GRATE DIMENSIONS AND BURNING RATES

Trip		Year Started	No. of Boilers	Mfg. of Grates	Grate Dimensions						No. of Separate Grate Sections	No. of Parallel Grate Runs	Rated Refuse Input		Max Rate		Design LHV			Design Burning Rate		Design Grate Heat Release Rate			
					Width		Length		Area																
					m	ft	m	ft	m2	ft2			mt/h	t/	mt/	t/	Kcal/Kg	KJ/Kg	Btu/lb	Kg/m^2-h	lb/ft^2-h	Kcal/m^2-h	MJ/m^2-h	Btu/ft^2-h	
1 Werdenberg-Liechtenstein		1974	1	A-F	2.77	9.1	6.65	21.8	18.42	198.3	1	1	5	5.12	6.4	7.0	2800	11,724	5040	271	55.6	759,920	3182	280,226	1
2 Baden-Brugg		1970	2	A-F	2.5	8.2	7.3	24.6	19.73	201.8	1	1	3.33	3.66	5.0	5.5	2600	10,886	4680	266	54.6	691,600	2895	255,520	2
3 Duesseldorf	Boiler 1-4	1965	4	VKW	3.5	11.5	11.0	36.0	38.7	416	7	1	10	11	-	-	1850	7,746	3330	258	52.8	478,000	2001	176,309	3
	Boiler 5	1972	1	VKW	3.5	11.5	10.7	35.1	37.6	430	6	1	12.5	13.75	-	-	2111	8,835	3800	332	68.1	702,000	2940	259,030	
4 Wuppertal		1976	4	VKW	3.5	11.48	10.2	33.5	35.7	384	6	1	15.0	16.5	-	-	2250	9,421	4050	420	86.2	945,000	3955	348,500	4
5 Krefeld		1976	2	VKW	3.5	11.48	10.2	33.5	35.7	384	6	1	12.0	13.2	-	-	2250	9,412	4050	336	68.8	756,000	3165	278,813	5
6 Paris:Issy		1965	4	M	6.3	20.66	8.4	27.6	52.9	569	1	3	17.0	18.74	19.9	21.9	1800	7,537	3240	321	65.7	578,520	2422	213,068	6
7 Hamburg:Stellinger-Moor		1972	2	M	4.7	15.6	8.9	29.3	43.9	472	1	2	18.8 24.6	20.6 27.1	24.8 24.8	27.2 27.2	1800 1500	7,537 6,281	3240 2700	427 360	87.3 114.6	768,600 840,000	3218 3517	282,852 309,420	7
8 Zurich:Hagenholz		1973	(1)	M	5.3	10.0	8.4	27.6	44.9	483	1	3	21.0	23.1	-	-	2300	9,630	4140	468	95.6	1,075,710	4504	395,786	8
9 The Hague	Boiler 1-3	1968	3	VR	3.0	9.8	10.5	34.0	31.5	339	3	1	15.0	16.5	-	-	1800	7,537	3240	476	97.3	856,800	3587	315,752	9
	Boiler 4	1971	1	VR	3.4	11.1	12.0	39.4	40.8	439	3	1	15.0	16.5	-	-	2300	9,630	4140	367	75.2	844,000	3536	311,326	
10 Dieppe(and Bonneville)		1974 1976	2	VR	2.0	6.6	8.0	26.2	16.0	172	2	1	2.8	3.1	3	3.3	2000	8,374	3600	173	35.8	350,000	1465	128,930	10
11 Goteborg		1970	3	VR	3.4	11.1	10.9	35.8	36.9	397	3	1	12.5	13.8	15.0	16.5	2500	10,468	4500	339	69.0	847,500	3548	310,500	11
12 Uppsala		1970	(1)	B&S	2.0	6.5	8.1	26.6	16.2	174	1	1	5.0	5.5	-	-	2450	10,258	4410	309	63.1	757,050	3170	278,271	12
13 Horsens		1974	1	B&S	2.0	6.5	8.1	26.6	16.2	174	1	1	5.0	5.5	-	-	2800	11,724	5040	309	63.1	865,200	3623	318,024	13
14 Copenhagen:Amager		1970	3	V	2.7	8.9	7.0	23.0	18.9	203	2	1	12.0	13.2	13.0	14.3	2000	8,374	3600	635	130.0	1,270,000	5317	468,177	14
15 Copenhagen:Vest		1970	3	V	2.7	8.9	7.0	23.0	18.9	203	2	1	12.0	13.2	13.0	14.3	2000	8,374	3600	635	130.0	1,270,000	5317	468,177	15

*Manufacturer abbreviations: A-F(Alberti-Fonsar); VKW(Vereinigte Kesselwerke); M(Martin); VR(Von Roll); B&S(Brown & Sorensen); V(Volund).

(1) Describes only the last furnace - boiler line purchased.

Another more bold approach is to design for much higher intensities of burning but to use precise control of primary and secondary air to assure relatively uniform, but intense combustion and rapid furnace-gas mixing. This involves the careful control of high-pressure primary and secondary air. In effect, this philosophy aims for accurate control of air-fuel ratio throughout the active burning areas of both grate and furnace. A critical factor in successful application of this intense burning mode is primary air pressure. To some extent, the successful pressure ranges used are considered proprietary by some manufacturers. Table Q-3 shows the nominal design pressure of the primary air for each plant. The actual average operating pressure is somewhat less than the design pressure.

The highest primary air pressure shown is for Unit No. 3 at the Hagenholz plant at Zurich, started up in 1973. The detailed plant report indicates outstanding performance by this particular unit which probably can be ascribed, in part, to the excellent combustion control provided by the grate which utilizes a high primary air pressure. However, many other factors are also contributory.

Grate Life

In most of the plants visited, the annual cost of grate maintenance was a minor cost but the range of replacement required was considerable. Table Q-4 shows the grate-bar replacement experience.

In addition to grate bar replacement, some grates require periodic cleaning to keep the air-flow openings free. Melted aluminum and other metals and mixtures require periodic shut-down for cleaning. For example, at the Horsens plant, the original grate bars required 2 man-hours per week for cleaning which was done during regular week-end shutdowns. Use of a newer design of grate bar has reduced the cleaning required to every other week.

Grate Materials

Because of the frequent exposure of the grate bars to burning material, the bars are usually made of high-chromium content cast steel. However, the Duesseldorf roller grate is primarily of cast iron with only the wear sections at the sides made of cast chrome-nickel alloy. Also, the Volund grate is made of heat resistant Meehanite, a specific form of grey iron casting.

Grate Action

As can be seen in the following grate descriptions, there is a wide range of concepts for achieving motion of the heterogeneous mass of burning refuse.

Almost all furnaces have a ram-type refuse feeder to achieve positive entry of refuse onto the grate. However, some of the systems depend, instead, on the slope of the grate. The grate bar motion then ensures movement of the refuse along the grate surface. Virtually all grates are steeply sloped, up to 30 degrees. K&K, however, under one of its configurations, deliberately holds the refuse horizontally while agitating it along by reciprocating grate motion.

TABLE Q-3. DESIGN PRESSURE OF PRIMARY AIR SYSTEM AT PLANTS VISITED

Plant		Primary Air Pressure		
		mmH_2O	$in.H_2O$	kPa
1	Werdenberg-Liechtenstein	170	6.7	1.67
2	Baden-Brugg	280	11	2.74
3	Duesseldorf	180 240	7 4.5	1.74 2.37
4	Wuppertal	140	5.5	1.37
5	Krefeld	300	11.8	2.94
6	Paris:Issy	410	16.1	4.00
7	Hamburg:Stellinger-Moor	530	21	5.23
8	Zurich:Hagenholz	580	23	5.72
9	The Hague	370	14.4	3.585
10	Dieppe (and Deauville)	150	5.9	1.471
11	Gothenburg	400	15.7	3.91
12	Uppsala	-	-	-
13	Horsens	200	7.9	1.97
14	Copenhagen:Amager	230	9.0	2.24
15	Copenhagen:West	230	9.0	2.24

TABLE Q-4. GRATE BAR REPLACEMENT

Trip		Year Operations Began	Grate Bar Replacement Rate
1	Werdenberg-Liechtenstein	1974	None in three years
2	Baden-Brugg	1970	---
3	Duesseldorf	1965 1972	Three rolls out of 35 in 12 years
4	Wuppertal	1976	None. Clean two times/yr.
5	Krefeld	1976	None. Clean two times/yr.
6	Paris:Issy	1965	60 to 70 bars/yr out of 900 per furnace
7	Hamburg:Stellinger-Moor	1972	24 per cent replacement/yr of all grate bars
8	Zurich:Hagenholz	1973	Seven per cent replace/yr of all grate bars
9	The Hague	1968	None except annual removal of sliding support plates
10	Dieppe (and Deauville)	1971(76)	One half of grate replaced over 7 years
11	Goteborg	1970	60-70 per cent of grate replaced in first five years (Total cost $50,000 -$60,000)
12	Uppsala	1961	Replaced one of three grate sections over 16 years
13	Horsens	1974	20 out of 720 bars replaced per year
14	Copenhagen:Amager	1970	Estim. 100% bar replacement every 15,000 hours
15	Copenhagen:West	1970	Estim. 100% bar replacement every 20,000 hours

All grates observed provide agitation of the burning mass. This is in recognition of the need to do two things:

- Continually expose fresh surfaces to ignition and air flow
- Keep filling in voids that form rapidly when zones of lightweight highly combustible material burn out. This leaves voids through which primary air can bypass the bed unless such holes are promptly filled by rearrangement of the heterogeneous mass.

Even the older traveling grate which provides no fuel bed agitation was installed as a multiple series of stepped traveling grates so that as the burning refuse tumbled from one grate down to the next, there was momentary agitation and rearrangement of the bed.

Specific Vendor Grates

Von Roll Grate

Figure Q-2 shows in more detail the standard Von Roll sloping, reciprocating grate installed as two steps in a large furnace. The original Von Roll grate, which is still in use in many of the larger Von Roll plants, involves the alternating forward motion of adjacent grate "plates". This naturally caused wear by the abrasive action of ash and clinker particles sifting between the plates as they slide relative to each other. As a result, the air gaps between the grate plates at The Hague plant, originally 3 mm (0.12 in) increased in nearly 10 years to, in some cases, 40 mm (1.6 in). This impaired control of the distribution of primary air and, at times, the air-flow resistance through portions of the grate and fuel bed is so low that the air pressure below the grate becomes less than atmospheric. However, there has been little grate repair work done in nearly 10 years of operation except for annual renewal of the sliding plates attached to the bottom of the grate bars.

For smaller furnaces (that is, 5 tonnes per hour or less), Von Roll began 15 years ago to install the improved grate composed of alternate fixed and moving rows in which each entire moving row of grate plates moved forward and backward together, thus eliminating the relative motion and grinding action between adjacent grate blocks. There is still a wearing action then due to the relative motion of each moving row on the stationary row beneath it, but the air gap there is kept minimal by the gravitational force holding each upper row tightly against the next row below. Von Roll is now applying this grate, as shown in Figure Q-3, to all new furnaces regardless of size.

Drying Grate. In the early Von Roll plants, there was first a large drying grate because it was anticipated that often the refuse would be very wet. Also, directly above the drying grate there often was a gas-burning chamber so that hot flue gas could be forced directly downward against wet refuse on the drying grate. However, today's refuse has not been as wet as in earlier years. Accordingly, the gas burning chamber is now unused or eliminated, and the size of the drying grate has been reduced.

Burnout Grate. Figure Q-4 illustrates another feature of the early Von Roll grate, the use of grate knives which are raised intermittently to lift and

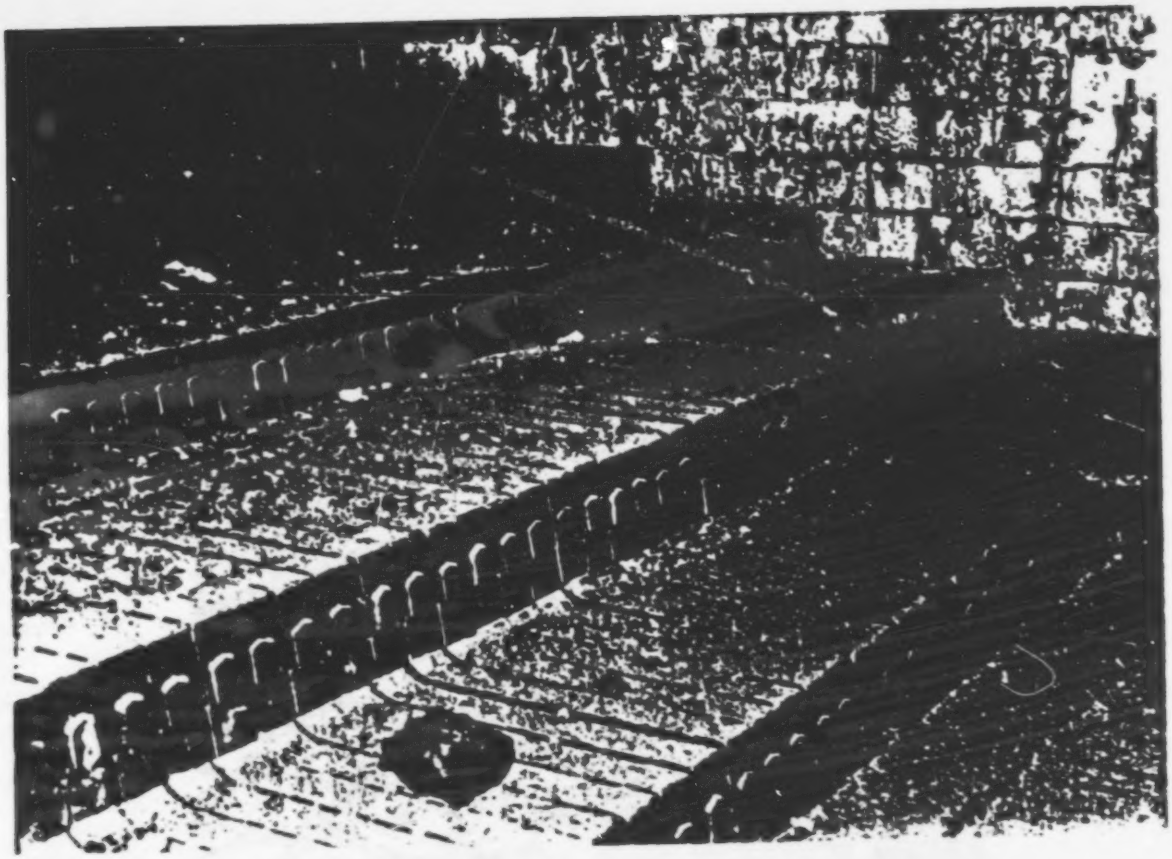

FIGURE Q-2. VON ROLL RECIPROCATING STEP GRATE IN REFRACTORY WALLED FURNACE (COURTESY VON ROLL, LTD.)

Circa: 1975-Present

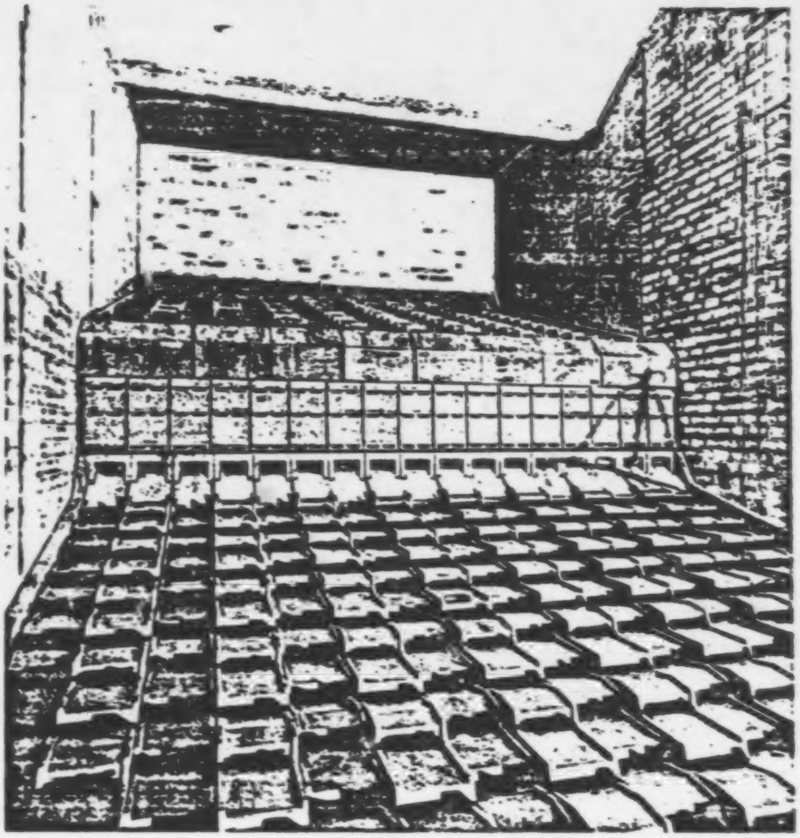

FIGURE Q-3. TWO STEPS OF VON ROLL GRATE USING RECIPROCATING FORWARD-FEED DESIGN. (Courtesy of Von Roll)

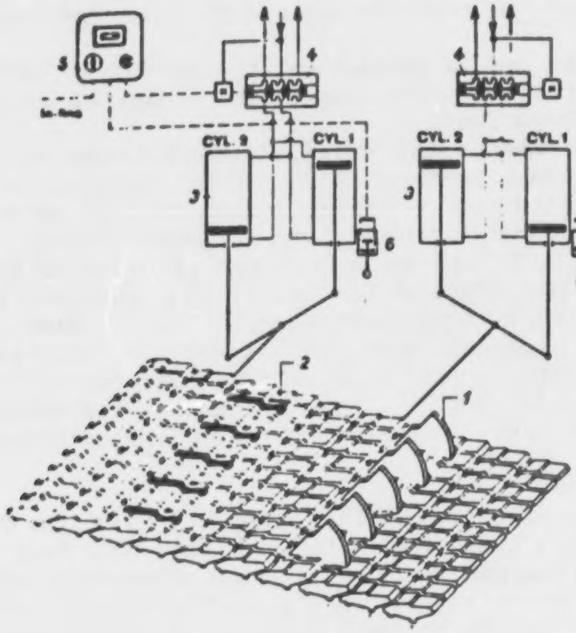
5
4
In-line
CYL. 2
CYL. 1
3
6
4
5
In-line
CYL. 2
CYL. 1
3
6
2
1

FIGURE Q-4. ARRANGEMENT AND DRIVE OF GRATE BLADES IN ORIGINAL VON ROLL GRATE (FROM R. TANNER, SONDERDRUCK aus SCHWEIZERISCHEN BAUZEITUNG, 83 JAHRGANG, HEFT 16, 1965)

(1) Grate Blades Raised
(2) Grate Blades Lowered
(3) Cylinder for Pneumatic Drive
(4) Solenoid Control Valve
(5) Control Box
(6) Limit Switch

Circa: 1948-1965

agitate the fuel bed at the last stages of burnout. Tanner * described the philosophy of these blades in 1965. Tests have shown:

> "... burnout on ordinary grates is poor for the two following reasons:
>
> (1) At the end of combustion, the clinker is covered with a layer of ash which hampers the access of oxygen to the remaining fuel.
>
> (2) Depending on the original composition of the refuse, there is a tendency to form lumps ranging in size from a fist to a football, which burn up on the surface while remaining completely unchanged inside.
>
> Both these effects can be avoided by means of grate blades arranged on the last grate or the last grate portion. In a cycle that is adjustable, they beat against the clinker layer from below, knocking the ash from the clinker and splitting up any refuse lumps. This ensures a satisfactory burnout of the clinker. From the angle of design, the grate blades have the advantage that they fit freely into the grate and do not prejudice any widening of the latter."

Grate Steps. As illustrated in Figure Q-3, the Von Roll system features one or more steps between grates to rearrange the fuel bed as it tumbles downward from an upper to a lower grate. Because of the "opening up" of unburned combustible surfaces as this tumbling action occurs, this point in the furnace is one of intense burning. To provide enough air at this point, in some plants, air is being admitted through the wall of the step to assure ample oxygen supply for the increased combustion rate.

Grate Zones. Primary air under the grate is supplied to a number of separate air zones, usually six or seven, with a manually set damper controlling the flow to each zone. An automatically controlled damper controls the total primary air supply.

Kunstler Grate

At The Hague, one furnace, after about 55,000 hours of operation, will shortly be converted to use a Kunstler grate manufactured by K&K Ofenbau AG, Zurich, This type of grate, shown in Figure Q-5,which is from the Basel, Switzerland plant, similar to the improved Von Roll grate, consists of horizontal rows of grate blocks which are moved forward in unison, thus eliminating relative motion between adjacent blocks. At the same time, the Kunstler air wall system is to be installed at The Hague in the walls near the grate. This will be discussed later under "Furnace Wall".

A new form of reciprocating grate, not seen at any of the 15 plants visited, is the new Kunstler grate shown diagramatically in Figure Q-5. Instead of sloping downward, the three sets of grates slope slightly upward. The design intent apparently is to prolong the retention of burning waste in each section before it is tumbled downward over the step to the next lower grate section.

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*Tanner, R., "The Development of the Von Roll Refuse Incineration System," Sonderdruck aus Schweizerischen Bauzeitung, 83 Jahrgang, Heft 16 (1965).

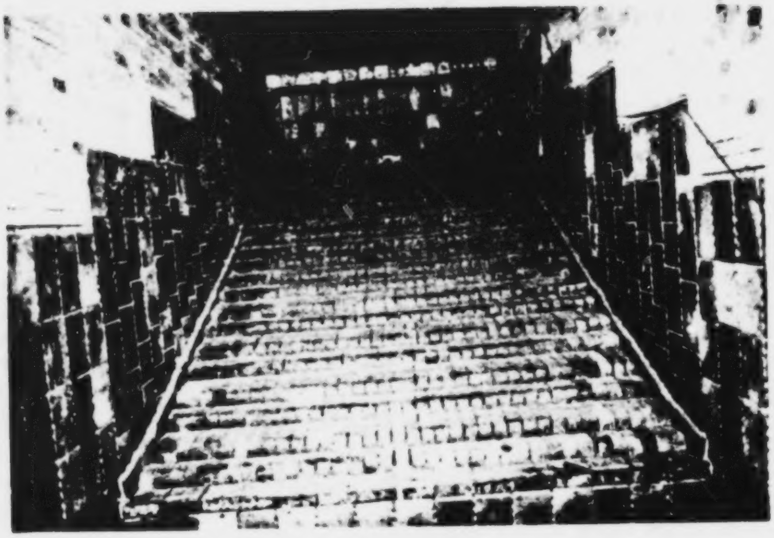

FIGURE Q-5. KUNSTLER GRATE AND AIR-COOLED WALL PLATES APPLIED TO AN INCINERATOR (COURTESY K&K A.G. ZURICH)

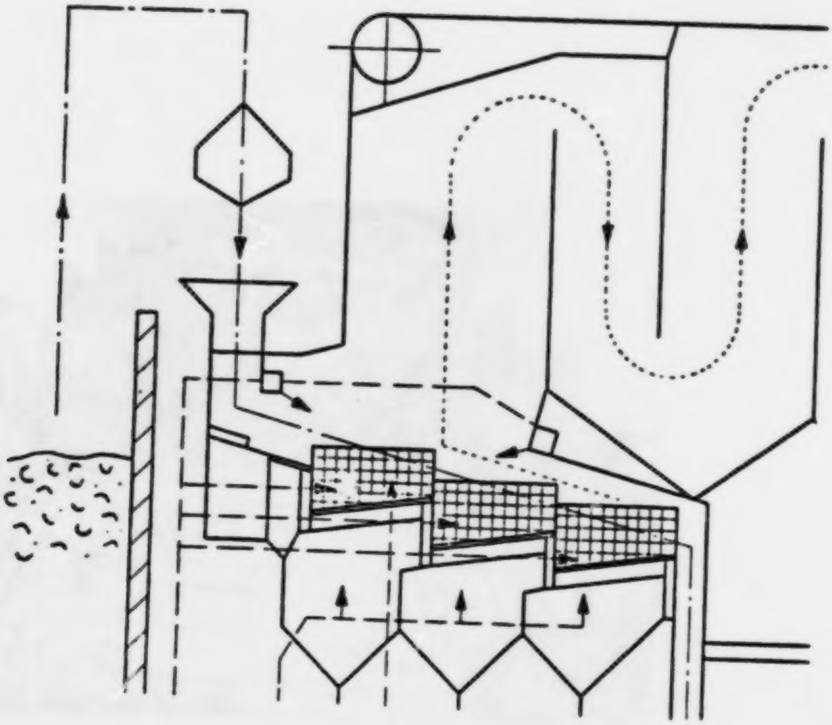

FIGURE Q-5a. DIAGRAMMATIC VIEW OF APPLICATION OF A 3-STEP KUNSTLER & KOCH GRATE TO 3-PASS BOILER.
(Courtesy Kunstler & Koch)

Martin Grate

The Martin "Reverse Reciprocating" stoker grate, shown in Figure Q-6, is inclined downward at an angle of 26 degrees from the feed end towards the clinker discharge end. It is comprised of alternately fixed and moving steps of grate bars. The activated steps move slowly counter to the downhill refuse movement.

In this manner, the fuel bed is constantly agitated, rotated, and again leveled out. The glowing mass is pushed back from the main burning area towards the front or feeding end of the grate. The different phases of combustion, i.e., drying, volatilization, ignition, and burnout, thus take place at the same time in close contact with one another. Freshly fed refuse is dried out and ignited from below by the burning fuel maintained at the grate front end.

The grate bars are made of a heat resisting cast steel alloy of 16 to 18 percent chromium. Air entering the grate bars passes through the serpentine channels in the underside of the bar before passing through the air slot (less than 2 mm wide) between adjacent bars into the fuel bed.

Grate Zones. The grate bars are designed and assembled so that no more than 2 percent of the grate area is open for air flow. Thus, with separate air flow control in each of the five to seven air plenums and with the many small air holes, the primary air pressure drop can be kept at a very high level for maximum control of air-fuel ratio and relatively uniform distribution of air through the area of each grate zone.

The undergrate air is admitted to each zone through damper openings of different sizes in accordance with air supply requirements over the whole grate surface. The opening angle of these dampers is selected by a central controller and is proportioned to the desired heat release. Each section of grate with its air plenum and siftings hoppers are supported by a structural steel system of ample strength to carry all of its parts and a refuse bed of 500 kg/m^2 unit weight. Grates and supports are sufficiently strong to withstand the impact of freely falling refuse from the top of the feed hopper and bulks of slag from the furnace walls, respectively.

The burned out residue travels slowly down the grate under constant agitation. After reaching the grate end, a slowly rotating clinker roll seizes the residue and dumps it into the quench pit. The gentle grate action reduces dust and charred paper generation from the fire bed. This helps reduce dust carried through the boiler and into the precipitator. The grate action also minimizes the formation of excessive hot spots and excessive clinker buildup and helps to produce a residue having about 3 percent unburned carbon. Side faces of the bars are machined to achieve even, uniform widths of air gaps between adjacent bars and are arranged to prevent spreading or bunching of individual bars. At the sides of the grate sections, self-compensating expansion blocks prevent binding of the grate bars due to heat expansion. This helps to maintain a constant air gap and ensures that the openings for combustion air are limited to approximately 2 percent of the grate area surface. The air openings in the Martin grate bar design are fixed at the front of the bar so that the combustion air spreads over the whole underside of the firebed,

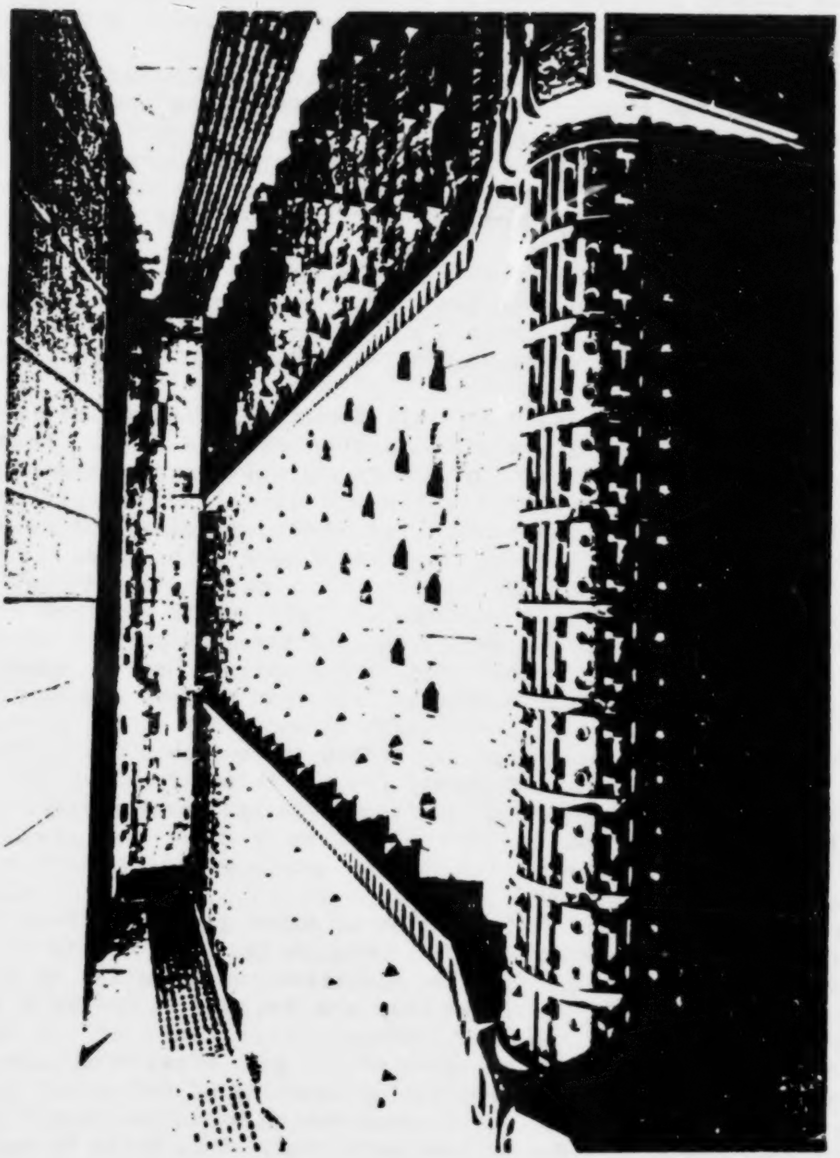

FIGURE Q-6. MARTIN THREE RUN GRATE SYSTEM (COURTESY JOSEF MARTIN, GMBH) regardless of any dense objects in the bed. Figure Q-7 shows that some of the bars have a pyramid head fixed on top to break up clinkers.

At the upper and lower end of each stroking movement, the adjacent bars in all grate steps will move, by mechanical action, a distance of about 20 mm to each other. This movement prevents blockage of the air gaps by fine ash. Figure Q-8 shows a side view of a Martin grate.

The operator has much flexibillity in grate control because the grate strokes can be varied from seven to 80 strokes per hour.

A significant point in the design philosophy of the Martin grate has been expressed by Stabenow:*

> "Drop-off ledges to cause agitation of the burning bed should be avoided, as they can cause a high percentage of dust to be released into the furnace gas stream, and may also result in undesirable slag buildup on the grate which, in turn, may restrict the proper air flow to the fuel."

Widmer & Ernst (Alberti-Fonsar) Grate

The Alberti-Fonsar stepped grate is in seven sections on an average fuel bed slope of about 24 degrees. It is fabricated in Italy by the Fonderie e'Officine di Saronne S.p.A. using a grate material which is 25 to 30 percent chromium, 4 percent nickel, with some manganese and silicon. Figure Q-9 shows that the grate is made up of steps which alternately are fixed and reciprocating. The reciprocating parts have a maximum stroke of 380 mm (15 in) with the normal stroke being 350 mm (14 in) which occurs about once every 2 minutes. As the upper step moves forward, it tends to tumble the burning refuse downward to the next step, thus providing gentle agitation. Grate temperature can be monitored by the control room operator from indicators connected to three thermocouples located under the grate, near the middle of the grate surface, and on a fixed grate section.

The grate sections are guaranteed for 16 months. The manufacturer expects the grate to last 5 to 10 years.

The air supply to the grate is delivered to three zones under the grate. The flow to each zone can be controlled from the control room by means of butterfly valves where the operator has an indication of zone air pressure and valve position.

Widmer and Ernst, as a turnkey contractor, uses the Alberti-Fonsar grate for systems under 200 tonnes, (220 tons) per day. For larger systems, such as their 400 tonne (440 ton) per day in each unit at the new plant at Hamburg:Stapelfeld, they use the Steinmueller grate that is manufactured in Hamburg.

VKW (Duesseldorf Grate or Walzenrost)

Figure Q-10 shows the essential characteristic of the "walzenrost" (roller grate) which was developed in 1961 at the Flingern Power Plant in Duesseldorf, using a four-roller pilot grate which has since been dismantled. It is manufactured by the Vereinigte Kesselwerke in Duesseldorf and is generally known as the "Duesseldorf Grate". It provides a sloping fuel bed as do most European mass-burning grates for refuse. But instead of using oscillating or reciprocating grate bars to agitate the burning

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*Stabenow, G., "Problems with High Temperaure Incinerator Gases in the Superheater Area," Proc, ASME Conference on Present Status and Research Needs of Energy from Waste, Hueston Woods, Ohio, Sept. 1976, ASME, New York, NY 10017

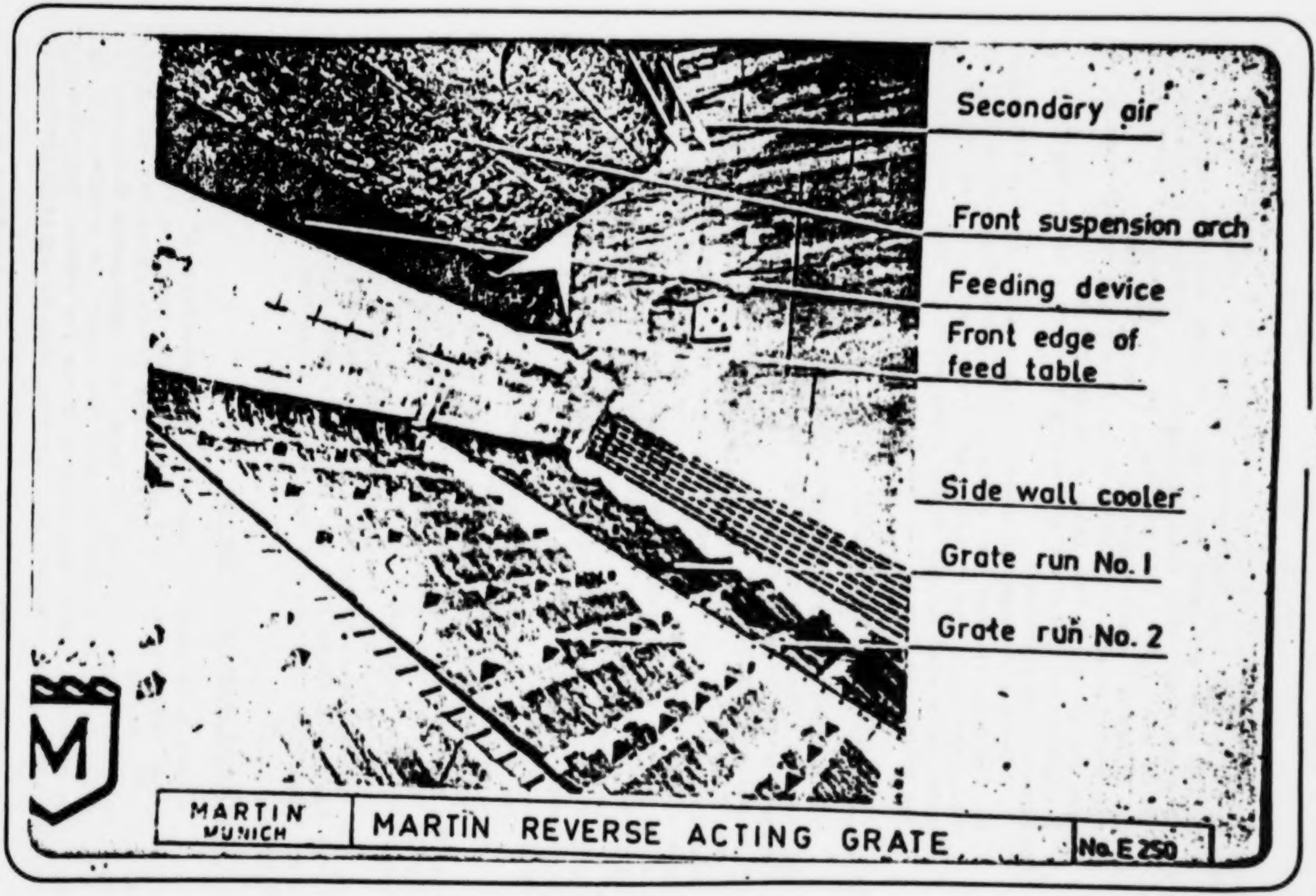

Secondary air
Front suspension arch
Feeding device
Front edge of feed table
Side wall cooler
Grate run No. 1
Grate run No. 2
MARTIN MUNICH
MARTIN REVERSE ACTING GRATE
No. E 250

FIGURE Q-7. SIDE VIEW OF THE MARTIN GRATE
(COURTESY JOSEF MARTIN GMBH)

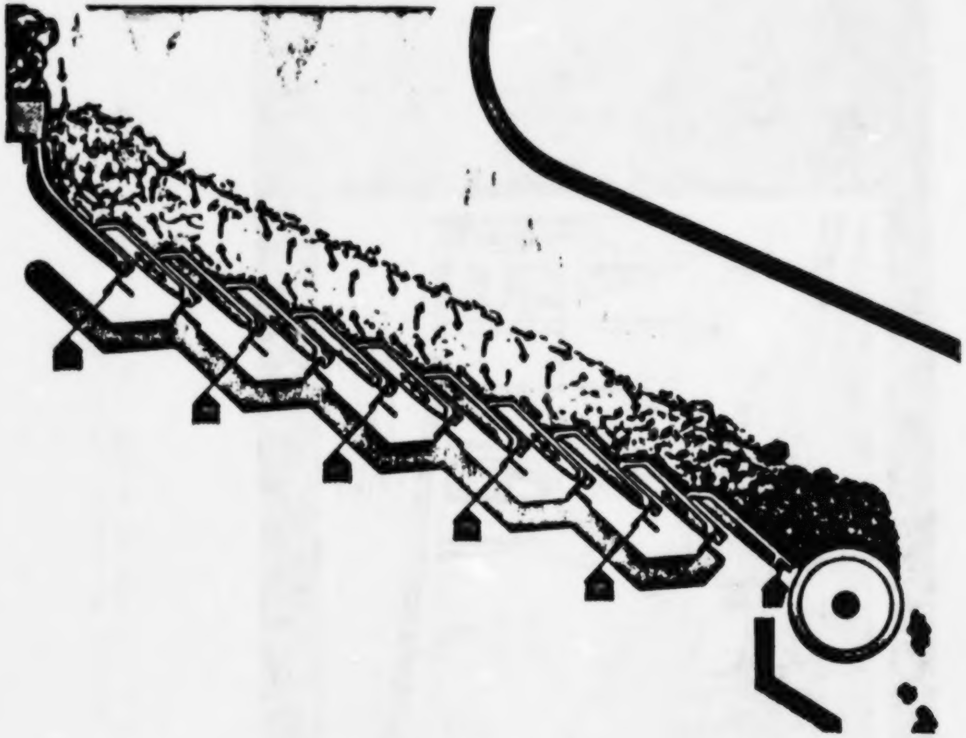


FIGURE Q-8. REFUSE TUMBLING ACTION OF MARTIN GRATE
(COURTESY JOSEF MARTIN GMBH)

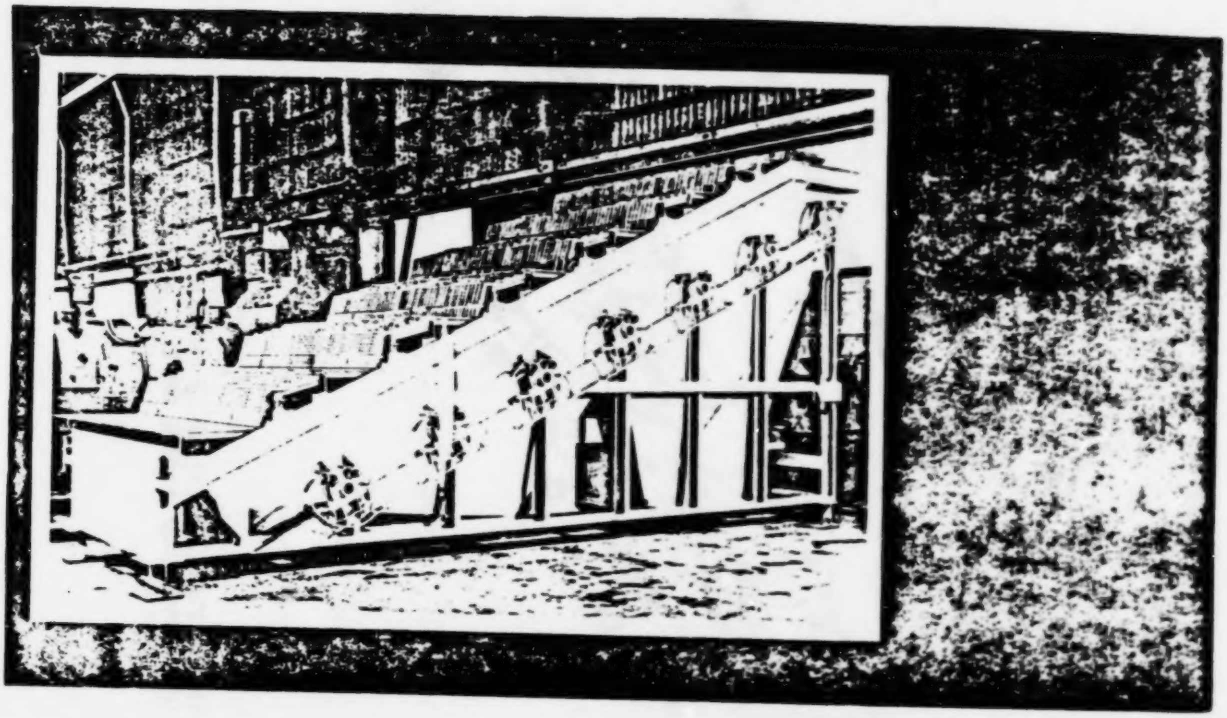


FIGURE Q-9. AN EXAMPLE OF THE ALBERTI FONSAR STEP GRATE SYSTEM ASSEMBLED AT THE FACTORY, COURTESY OF WIDMER + ERNST (ALBERTI-FONSAR)

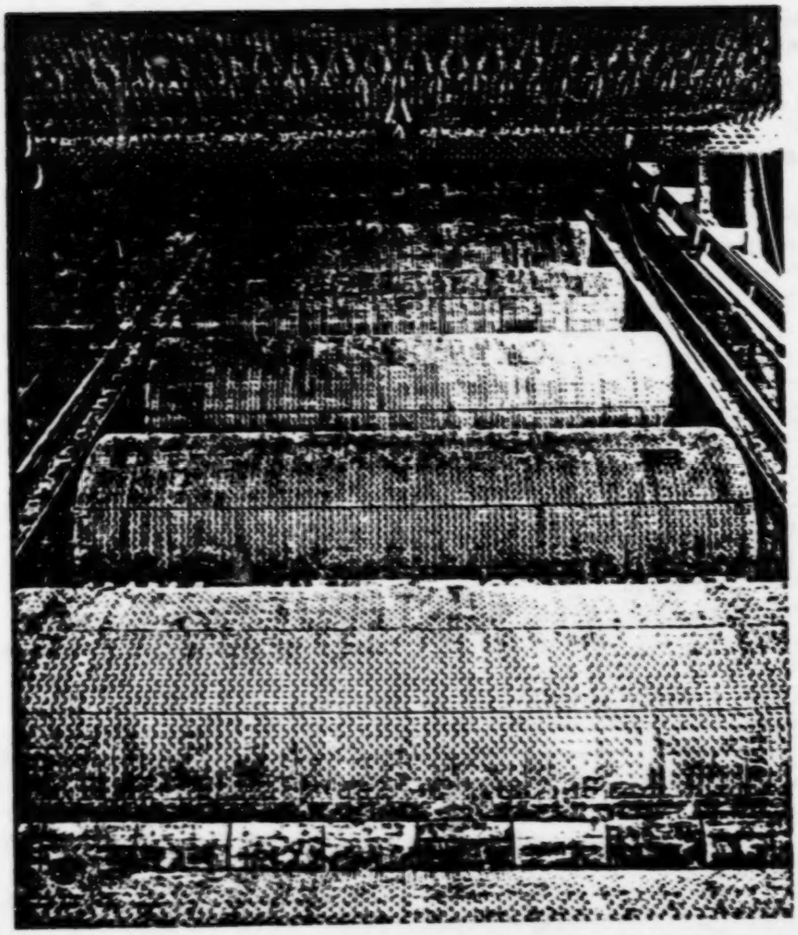


FIGURE Q-10. SIX DRUM WALZENROST (ROLLER GRATE); ALSO COMMONLY KNOWN AS THE DUESSELDORF GRATE. NOTE THE CAST IRON WIPER SEALS BETWEEN ADJACENT ROLLS WHICH PREVENT LARGE PIECES OF REFUSE FROM FALLING OUT OF THE FURNACE (Courtesy of Vereinigte Kesselwerke) material and to move the incombustible residues down the slope, the walzenrost moves the bed by slow rotation of the 1.5 m (4.92 ft) diameter drums which are formed of cast iron grate sections. Thus, there is opportunity for a slow tumbling action of the refuse which helps to keep the fibrous mass loose, thus allowing for more uniform distribution of primary air throughout the bed.

The drums rotate at an adjustable speed of about 3 to 6 revolutions per hour. Instead of being continuously exposed to the hot fuel bed, each grate bar rotates through a cool zone about half of the time. Thus, for minor repairs to the grates, the temperature on the underside of the grate is low enough to enable workmen to repair it while it is operating.

Each grate roll is formed of 10 sections, each of which contains 60 curved grate bars. The bars at each side which rub against the air seal plates are cast of chrome-nickel alloy to resist abrasion. Out of a total of 600 bars per roll, 12 are cast alloy. Early plants had seven rolls each, but in later designs there are six rolls per furnace.

The gap between adjacent rolls is filled by a cast iron wiper bar. This bar is strong enough to shear off refuse that may become attached to the grate. The only grate bar maintenance that is normally required is replacement of the first roll if scrap containing considerable magnesium is charged. In one case, 20,000 dry cells containing magnesium damaged a first roll so that replacement was necessary. Usually the grate rolls have operated 30,000 hours without major repairs.

The wiper seals are repaired three times a year. Normal wear of the seal gradually widens the gap which allows larger and larger pieces of refuse to fall through. A screw conveyor removes such residue from underneath the grate.

The hollow steel roller shafts are usually never replaced. Asbestos air seals at each end of the shaft require replacement every 5 or 6 years.

Each roller constitutes a separate supply zone for primary air. The air enters the interior of the roll from both ends and flows through the many small gaps between the interlocking grate bars. The amount of air flow through each roll can be adjusted.

As the burning refuse moves down the slope, the rotative speed of each successive roll is reduced so as to keep the fuel bed thickness approximately uniform.

This is an extremely rugged type of grate. The first roll is subject occasionally to severe impact from heavy objects being fed in by the feed ram and then dropping 1.8 m (5.9 ft) to the first roll. Little damage has occurred as a result of such impacts.

Bruun & Sorensen Grate

Figure Q-11a shows the oscillating type of rocking grate used by Bruun and Sorensen. As shown in the lower three sketches of the figure, the grate sections oscillate rotationally in a coordinated rocking motion such that the burning refuse is induced to cascade downward along the 30-degree sloping grate in a wave-like motion, thus slowly agitating the fuel bed so as to prevent compaction, voids, and consequent irregularity in air flow. The motion of each grate section is controlled by an adjustable timer.

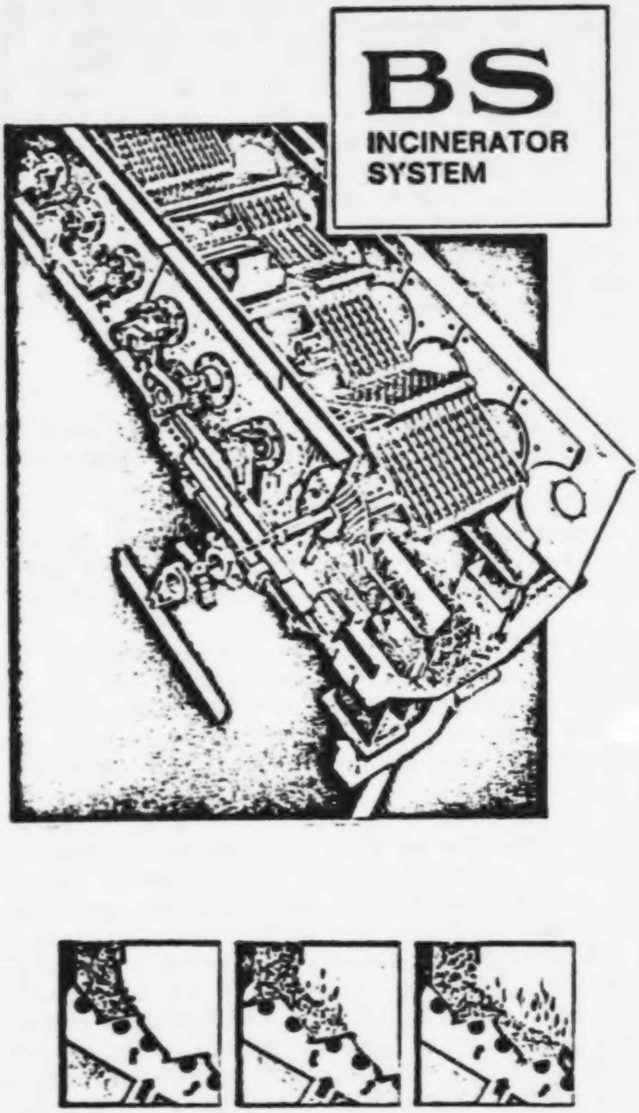

BS
INCINERATOR
SYSTEM

FIGURE Q-11 SKETCHES OF GRATE ACTION
(COURTESY OF BRUNN & SORENSEN)

The moving part of the grate is formed of three sections with six horizontal shafts in each section. The grate bars are fixed to the shafts. Figure Q-11b shows two typical grate bars which are 0.5 m (1.6 ft) long. The lower bar in the figure is 50 mm (2 in) wide. The upper one is a new design of bar which is 100 mm (4 in) wide. Recent experiences at Horsens, Denmark with a test section of the newer bar revealed that fine ash is less likely to adhere in the interstices between the bars; hence, less cleaning is required to maintain the gaps free for uniform air flow. New bars have been installed in all of the first grate section, and it is planned to change also the other two grate sections. The new and old bars are cast by a Swedish affiliate of Bruun & Sorensen using an alloy of 23 percent chromium, 1.5 percent silicon, 0.2 percent nickel, and 0.25 percent molybdenum. They are guaranteed for 10,000 hours.

Volund Grate

The sloping grate used by Volund is built up of fixed and movable sections. Mr. E. Balch, formerly Volund's Chief Engineer, described the grate as follows:

> "This grate construction is built up of several grate sections, each separated by a vertical grate transition bar. The ratio of size between the individual grate sections and grate transitions is determined by the composition of the refuse.
>
> Figure Q-12 and Q-13 show the individual grate section is built up of lengthwise-placed sections of 180 to 300 mm wide laid up with an inclination of 18-15 degrees. Every other of these sections are fixed and every other are movable, and each section is built up of a through grate bar, which is welded up, on which a number of grate blocks of specially alloyed cast iron are fitted, which are in turn filled up with loose grate bars of cast iron.
>
> Figure Q-14. The movable sections are driven hydraulically by a transverse driving shaft placed under the grate, which is connected to the individual sections by pendulum driving bars. From a neutral position, the movement in forwards stroke is slowly raising, forward going, and then lowering and backwards going. In the backwards stroke, the movement is slowly lowering and backwards going and then raising and forwards going.
>
> Along the side of grate sections, which are built into the wall of the furnace, there are a number of side sealing beams, which through building in springs give the grate sections a transverse flexible assembling.
>
> Figure Q-15. The first grate section acts as a feeding and predrying grate and apart from the last part of the transition bar, it is covered with grate plates. Ignition and the first part of the combustion takes place at the first transition and on the second grate. The final combustion and burnout takes place on the third grate, and calcining and cooling of the clinkers begin at the last part of the third grate and continue on the subsequent clinker chute.
>
> The layer of refuse is 300 to 500 mm (12 to 20 in). The movable grate sections give a lifting, moving, and turning

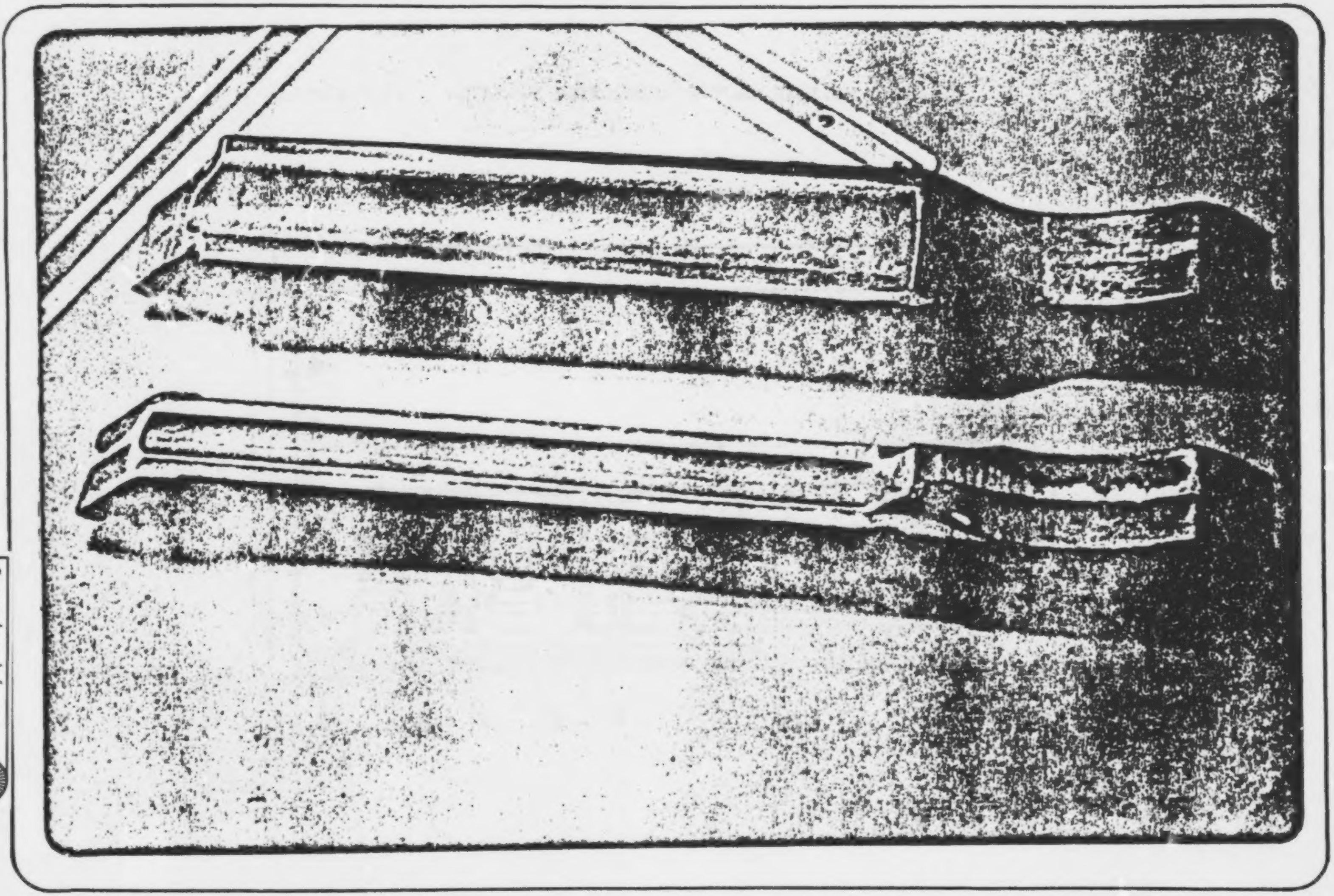


FIGURE Q-12. BRUUN AND SORENSEN CAST ALLOY GRATE BARS. THE OLDER BAR IS SHOWN BELOW. THE NEWER, WIDER BAR IS ABOVE (BATTELLE PHOTOGRAPH)

Reproduced from best available copy.

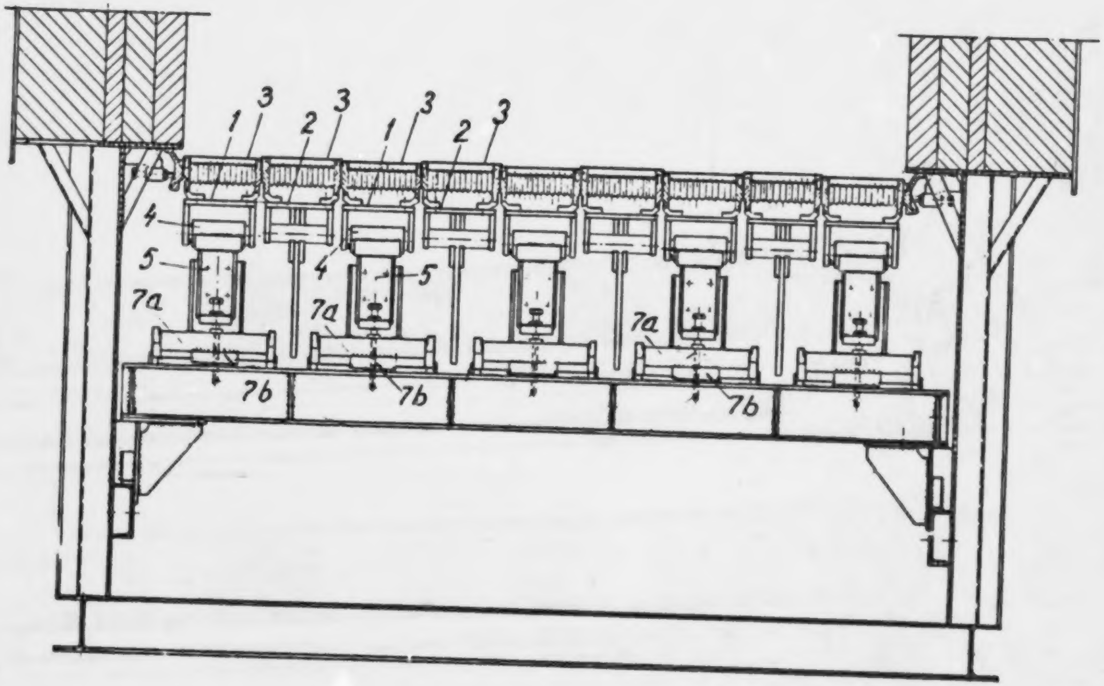

3
3
3
3
1
2
1
2
4
4
5
5
7a
7a
7a
7b
7b
7b

FIGURE Q-13. VOLUND'S LENGTHWISE PLACED SECTION OF GRATE

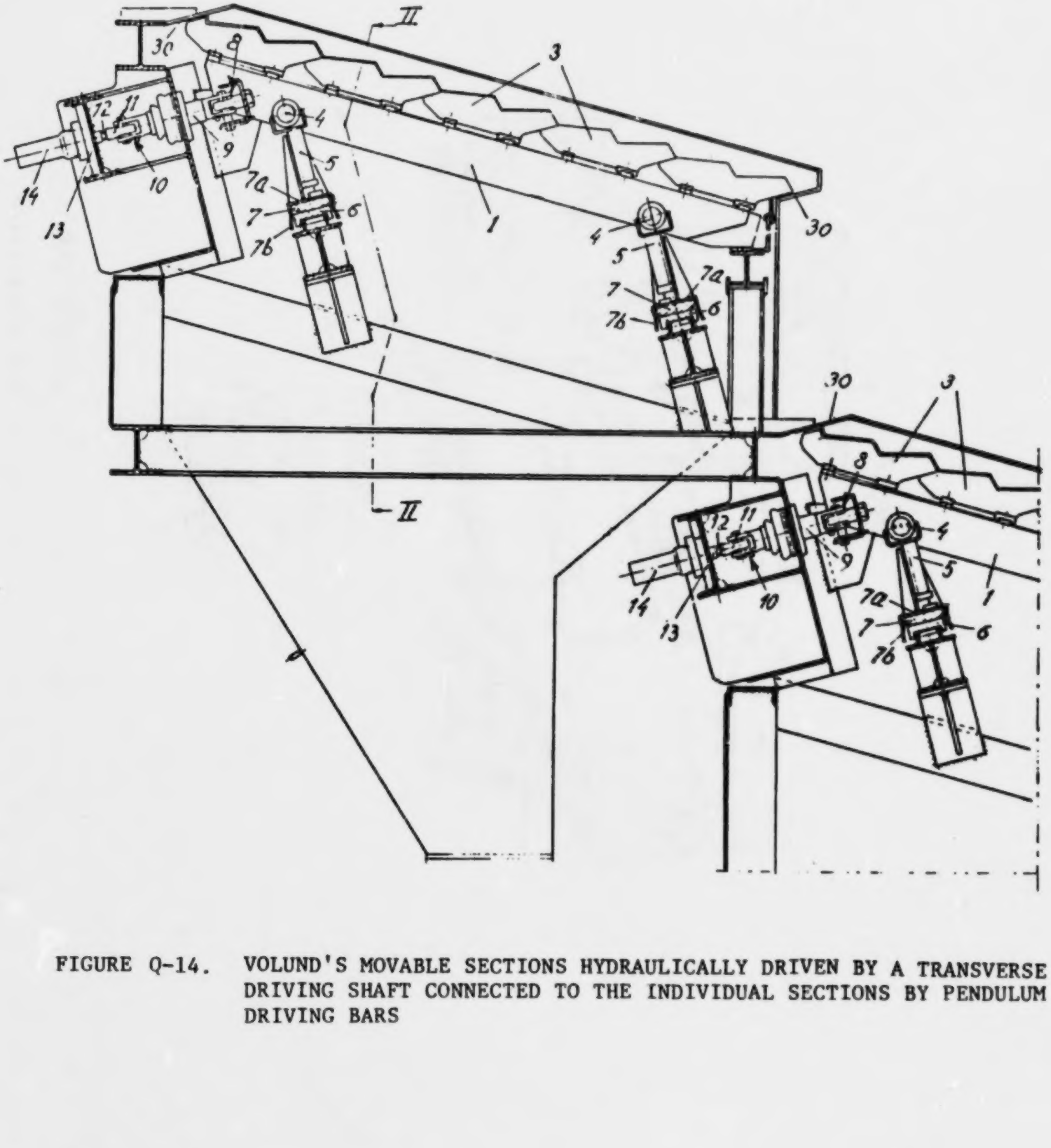

30
II
8
3
3
12
11
4
14
10
9
5
7a
13
7
6
7b
1
4
30
5
7a
7
6
7b
30
3
3
8
II
12
11
4
9
5
14
10
1
13
7a
7
6
7b

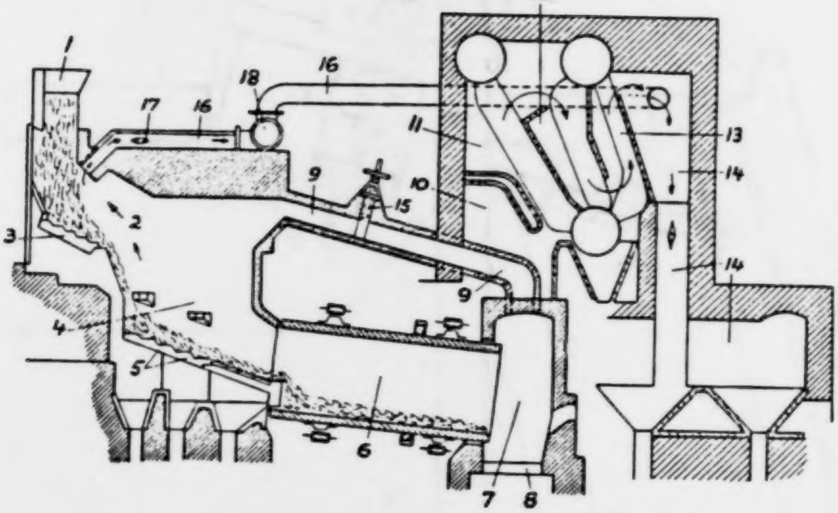
FIGURE Q-14. VOLUND'S MOVABLE SECTIONS HYDRAULICALLY DRIVEN BY A TRANSVERSE DRIVING SHAFT CONNECTED TO THE INDIVIDUAL SECTIONS BY PENDULUM DRIVING BARS

Oct. 1, 1935. **A. CHRISTENSEN** **2,015,842**

FURNACE WITH GRATE FOR COMBUSTION OF REFUSE OF ANY KIND

Filed Nov. 5, 1932

Fig. 1.


1
17
16
18
16
12
11
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14
9
15
2
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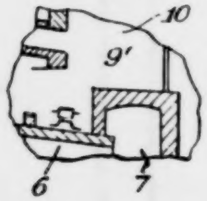
7
8

Fig. 2.



INVENTOR

Aage Christensen

FIGURE Q-15. ONE OF THE EARLIEST VOLUND PATENTS

> movement in the lower half of the layer so that the combustion air, which in a regulated way is supplied from below, can get to all parts of the layer. At the transition bars, there is a supplementary turning, mixing, and air supply."

Volund supplies furnaces with either three or four separate grates. Following these grates is the rotary kiln in which the burning is completed.

Each furnace has two operating hydraulic pumps. At some installations, an additional hydraulic pump is used as a standby. Each pump's capacity is 47 liters/minute (12.4 gallons/minute). Each pump has a 15 Hp motor. The resultant pressure is 1,160 pounds/in^2 (8,000 kPa). The plant has one 600-liter (160-gallon) hydraulic oil storage tank.

Each of the first three grates has five hydraulic cylinders with cylinder bases of 80 mm (31 in) and stokes of 130 mm (59 in). The stroke frequency is three strokes per minute.

Having three grates means that there are two steps. The height between Drying Grate I and Grate II is 1 m (3.3 ft). Between Grate II and Final Grate II, the height is 2 m (6.5 ft).

ASH

This section on ash is divided into five parts as follows:

- Ash Exit from Grate, Quenching Removal From the Furnace
- Ash Handling in the Plant, General Comments
- Ash Recovery, General Comments
- Ash Handling Recovery at Specific Plants

For purposes of this discussion and design of refuse energy plants, there are five kinds of ash, residue or slag that need to be defined:

- Ash, Residue, Slag are general terms loosely used to name the solid waste product after combustion. This is referred to as residues in America and slag in Europe. It may contain bottom ash, grate siftings and or flyash
- Bottom Ash is the solid waste falling off the grate end and into the chute
- Grate Siftings are the relatively small particles and dust falling under the grate normally through the spaces where the primary underfire air rises
- Fly Ash is the solid waste material that falls from boiler tubes and electrostatic precipitator either naturally or when blown off by soot blowers
- Processed Ash is the sorted nonferrous aggregate of stone, dirt, glass, etc. usually less that 1.5 cm (0.6 inch) ready for use as road aggregate or cinder block, etc.

Table R-1 summarizes ash handling and recovery options exercised at the 15 visited plants. Generally speaking ash handling is somewhat more advanced in Europe over the U.S.A. Ash recovery, however, is practiced much more in Europe than in this country. Of the 15 plants, 9 have ash recovery.

Ash Exit from Grate, Quenching and Removal from the Furnace

All systems arrange for the moving grate to discharge the hot, unburned residue into a water sump, quench tank or a spray chamber from which it is removed by a variety of methods. The residue, usually containing less than 3 percent combustible, is a highly variable material both in size and composition. Quenching is necessary because if the glowing residue were removed from the plant in its high temperature condition the dust and odors emitted from the hot surface would frequently be a nuisance.

Usually the residue is continuously removed from the tank. During that movement it is partially dewatered or drained by a drag conveyor or some form of hydraulically-driven ram or pusher. The wet residue then is discharged to a holding pit, movable bins or trucks for transport to a processing plant or to a landfill.

The quench container is the sink for the boiler blowdown water and other dirty water at most plants. Often this result in no wastewater (except for sanitary waste water) leaving the plant except in ash trucks. If scrubbers are not used, zero wastewater discharge can be a reasonable challenge for designers. This is the reason that this report does not have a chapter devoted to water pollution control --- in most systems there is no real water pollution.

TABLE R-1. SUMMARY OF ASH HANDLING AND RECOVERY METHODS

	Werdenberg-Liechtenstein	Baden-Brugg	Duesseldorf	Wuppertal	Krefeld	Paris:Issy	Hamburg:Stellinger-Moor	Zurich:Hagenholz	The Hague	Dieppe (and Deauville)	Gothenburg	Uppsala	Horsens	Copenhagen:Amager	Copenhagen:West	TOTAL
In Plant Ash Handling*																
• Reciprocating Push Room						X	X	X					X			
• Vibrating Conveyor						X	X	X				X				
• Steel Slat Conveyor				X	X				X							
• Rubber Conveyor	X	X	X			X		X	X	X	X			X		
• Skip Hoist													X		X	
• Detachable Container	X	X				X				X		X	X			
• Ash Pit				X	X											
• Ash Floor with Wheeled Front End Loader	X															
Quench Method*																
• Bottom of Chute Has Water						X	X	X			X					
• Water Pit									X							
• Trough	X			X					X							
• Ash Bunker is Wet				X							X					
Ash Recovery																
• Enclosed Building Recovery			X			X										2
• Outdoor Recovery				X			X	X	X					X	X	6
• Distant Recovery					X											1
• No Recovery at Plant	X	X								X	X	X	X			6
Recovery Operation Ownership																
• Plant Itself			X			X								X	X	
• Private Contractor, Receiver and Processor				X	X		X	X	X							
Separable Ash Components																
• Ferrous Fines (caps, lids, nails)				X				X							X	
• Ferrous Coarse (cans)				X				X							X	
• Ferrous All Sizes						X	X		X					X		
• Ferrous Bulky (bicycles, barrels)				X			X	X	X						X	
• Ferrous Baled			X													
• Road Aggregate			X	X		X	X	X	X						X	
• Bulky Non Ferrous (stumps, tires, paper rolls)				X			X	X	X						X	
• Medium and Coarse Non Ferrous (2" stones, bones)			X	X												
• Land Reclamation Material					X		X							X		

* The X pattern is not complete or definite.

Clinker Discharge Roll (Martin)

A full-width variable-speed residue discharge roll is fitted at the end of the grate to regulate the depth of refuse bed on the grate and to control the rate of residue discharge. The grate speed can be adjusted to suite the nature of refuse so that optimum mixing of the fuel layer can be obtained for fluctuations in load and composition.

The clinker roll is of heavy construction with replaceable cast iron segments. The material is designed to resist heavy abrasion and the temperature likely to be encountered at this point of the grate.

Ram for Residue Removal (Martin)

The simplest and most compact reside removal system uses a curved-bottom tank which is cleared by a slowly reciprocating pusher. Figure R-1 shows the schematic of the Martin ash discharger which uses that system. As the submerged residue is pushed upward toward the left by the ram it has time to drain off excess water before it drops into the pit, buggy, truck or other container. The discharge channel is tapered outward in the direction of motion to prevent packing and jamming. Figure R-2 shows the Martin unit discharging ash at Issy.

The following paragraphs are abstractions from Martin literature.

A chute is provided at the end of the grate to direct burned-out residue to the ash discharger. The bottom end is submerged in the water contained in the ash discharger quench trough to ensure a gas seal and to prevent ingress of cold air to the incinerator. The chute is lined with steel plates bolted to form an abrasion resistant surface and it is fabricated in thick plate adequately stiffened. An access door is included in the lower section of the chute to facilitate access above the water level in the ash discharger trough.

The Martin Ash Discharger receives the slag from the grate as well as the siftings from the different sections of the grate and the fly ash from the two boiler pass hoppers. The water bath forms an air-tight seal. The whole slag and ash discharging equipment is able to handle the largest pieces delivered by the discharging chute.

The inside cross sectional dimensional are 2 x 1 m (6.6 x 3.25 feet). The discharge rate can be as high as 6.3 tonnes (7 tons) per hour.

Water replacement for the relatively small water quenching bath is limited to the water evaporated and carried away with the clinker. This explains the very low water consumption rate of about 100 liters/1000 kg of refuse. The water content in the slag and ash is about 15 percent. There is no water flowing through the discharger and no polluted water effluent.

Under the discharger mouth, slightly inclined grids of 400 mm mesh are provided through which clinker falls onto a vibrating conveyor whereas bulky objects (bicycles, tires, stumps, barrels, etc.) are held back by the grid and may easily be removed by the personnel and dumped into carts or containers standing by.

The replaceable wearing plates are of 12 mm and 15 mm thickness. All parts are designed to withstand wear and tear during the operation period of at least 8000 hours.

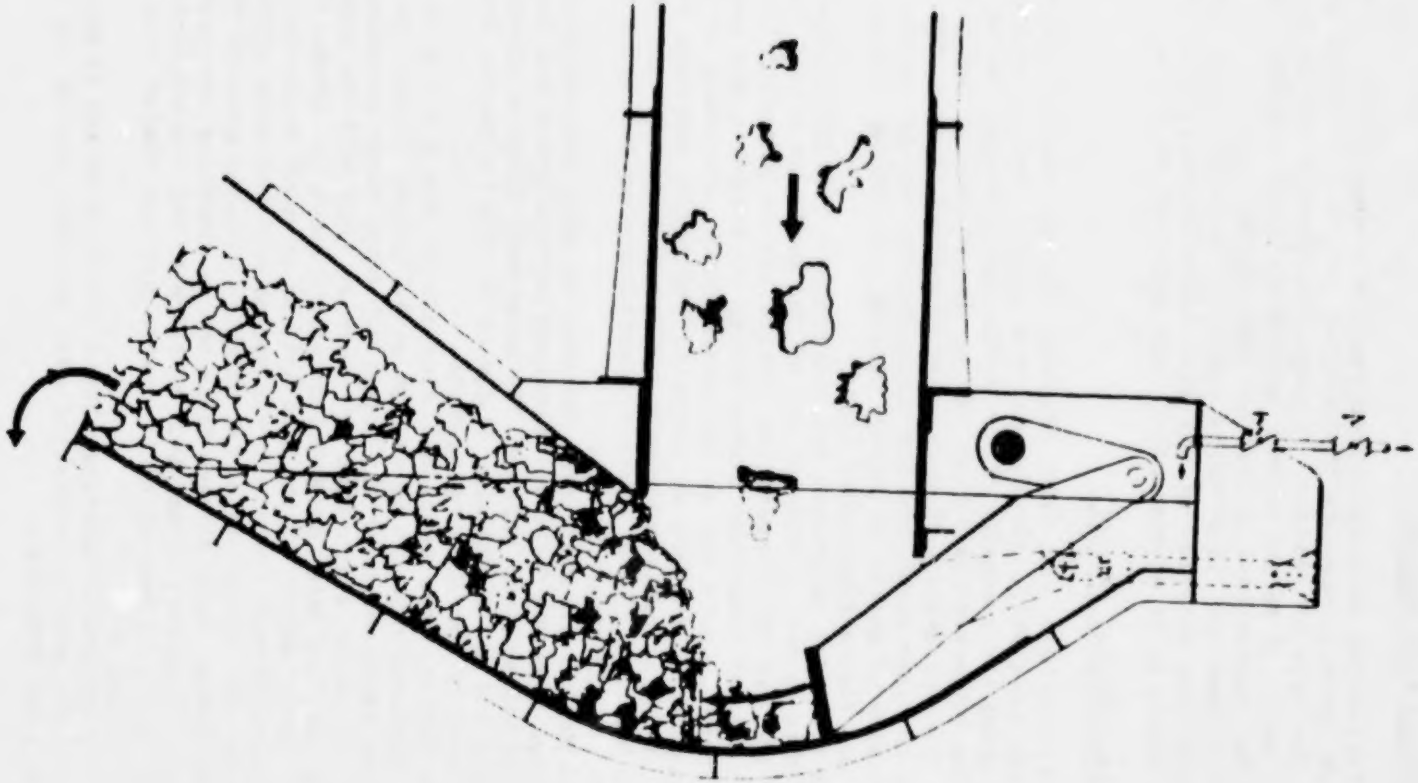


FIGURE R-1. MARTIN ASH DISCHARGER
(Courtesy of Josef Martin Feurungsbau, Gmbh)

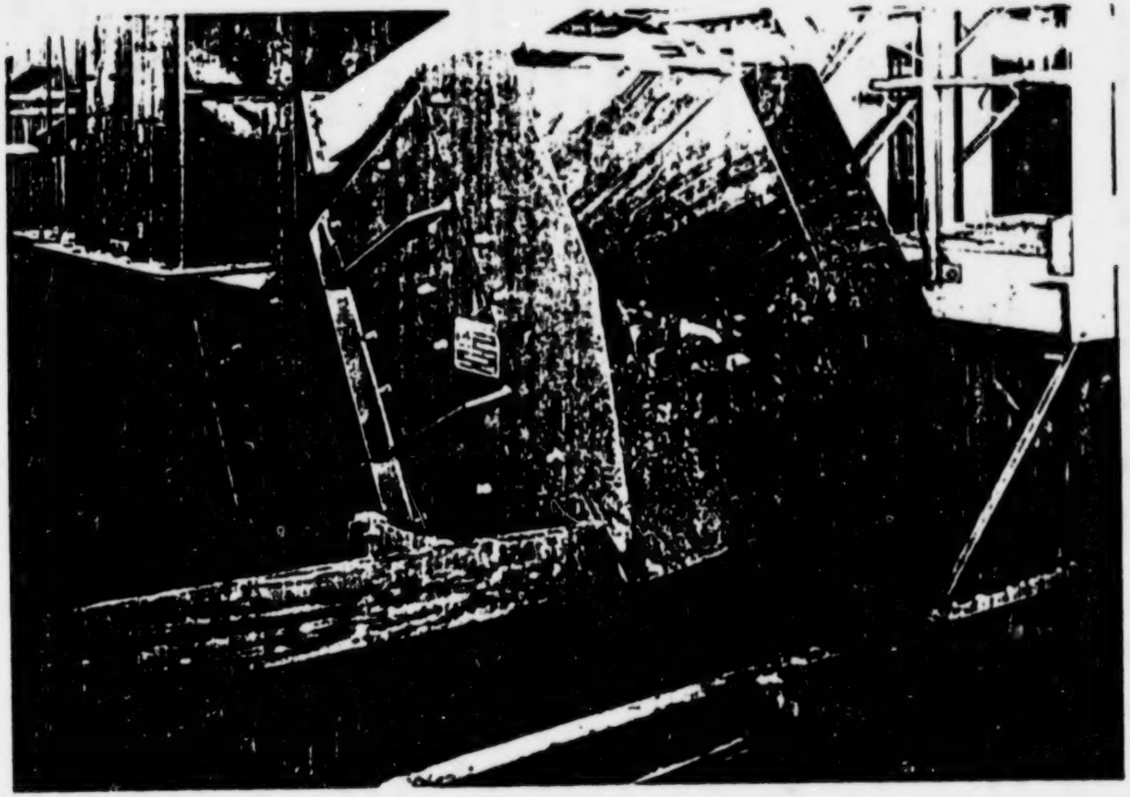


FIGURE R-2. MARTIN ASH DISCHARGER DUMPING INTO VIBRATING CONVEYOR AT PARIS: ISSY (Battelle Photograph)

The drive of the ash discharger is protected by an overload sensor and the discharging capacity is controlled by an infinitely variable speed regulator in the hydraulic distribution cabinet. The forming of excessive vapor is avoided. The ash discharge has a grate valve at the bottom of the trough for evacuation and maintenance purposes. The trough itself is constructed of steel plates with thickness of 10 mm and suitably reinforced.

Flysh Ash Handling (Martin and Others)

The coarse fly ash collected in the hoppers under the boiler passes is conveyed to the ash discharger via screws. On the other hand, the fine ash collected in the electrostatic precipitator is not fed into the ash discharger but rather into fly ash silos. The purpose is to avoid fouling of the ferrous scrap which is extracted from the refuse clinker. The fly ash collected in these silos is moistened by conditioning screws and discharged onto the clinker in the clinker pit.

Submerged Conveyor (Old Widmer and Ernst and Old Volund)

Figure R-3 shows another common type of submerged drag conveyor which slowly lifts the residue upward along a sloping channel so that it has time to drain.

Figure R-4 shows the discharge end of a similar conveyor at Aarau, Switzerland. An electric truck is used to remove the filled hopper. Note that the conveyor housing is reinforced concrete to resist the corrosive attack of the acids which accumulate the quench water. As explained in the next section, the acid condition is caused because the flyash containing sulfates and chlorides is also inserted into the bottom ash processing system. Designers of future bottom ash handling systems could probably worry less about corrosion if the flyash were handled elsewhere in a dry dusty form.

A system not too unlike this has caused serious problems at Copenhagen: Amager. The fines become enmeshed in the rollers and bearings and sometimes the fines build up so much that the systems must be shut down and the conveyor system cleaned.

Additional Ram-Type Dischargers

Since the early Widmer and Ernst plants were built a much simpler design of oscillating ram type of residue system has been used in their newer plants. Figure R-5 shows one form of this method applied to the small refractory-walled, non-energy recovery plant at Trimmis, Switzerland. A similar system will be used by Widmer and Ernst at the proposed Stapelfeld Plant at Hamburg which is shown in Figure R-6. Figure R-7 is a photograph of a similar device on a small Widmer and Ernst plant at Oberthurgau, Switerland.

Spray Quench with Conveyor

An alternate system which avoids some corrosion problems of the quench tank is the use of a water spray to quench the residue as it falls off the end of the grate. The moisture pickup of the residue is much less

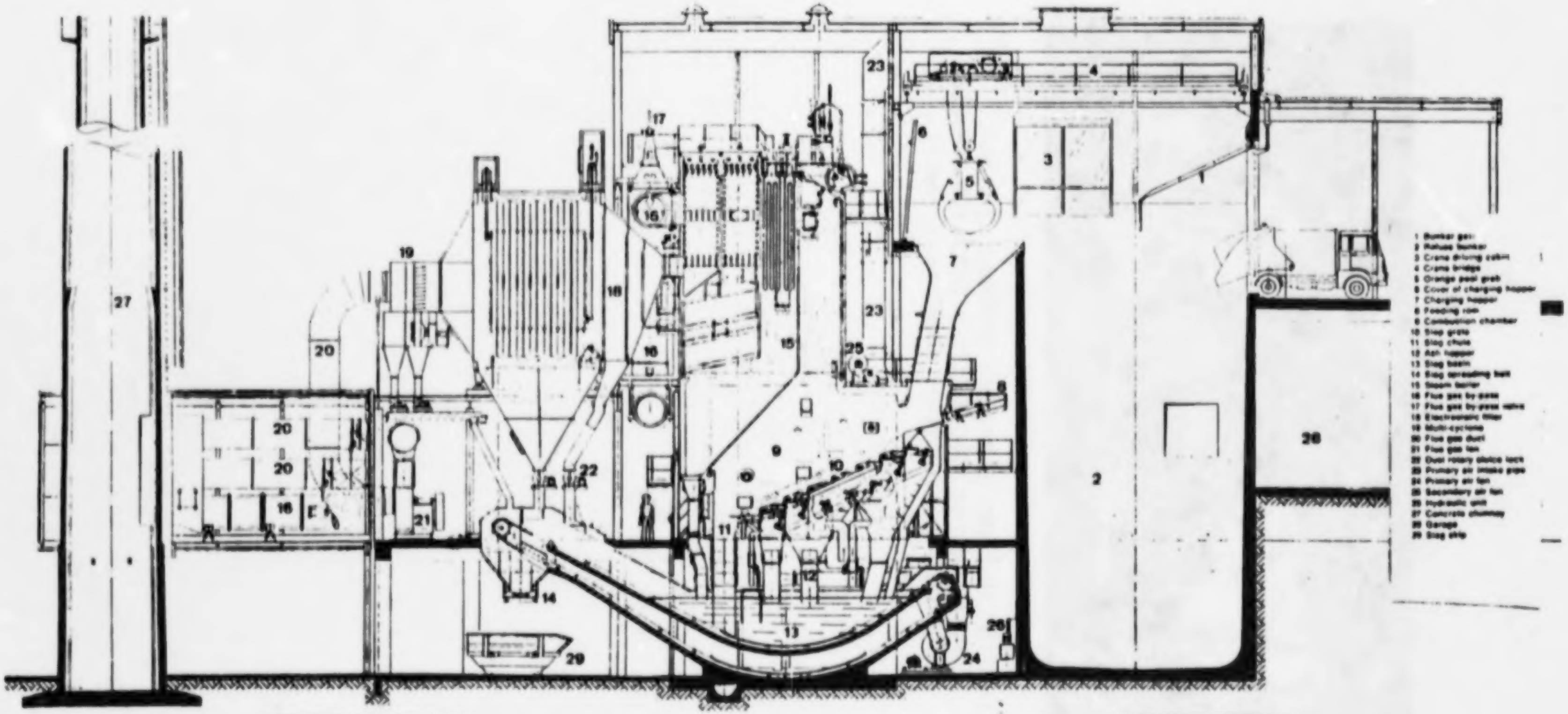

1 Bunker gate
2 Refuse bunker
3 Crane driving cabin
4 Crane bridge
5 Orange peel grab
6 Cover of charging hopper
7 Charging hopper
8 Feeding ram
9 Combustion chamber
10 Slag grate
11 Slag chute
12 Ash hopper
13 Slag basin
14 Slag spreading belt
15 Steam boiler
16 Flue gas by-pass
17 Flue gas by-pass valve
18 Electrostatic filter
19 Multi-cyclone
20 Flue gas duct
21 Flue gas fan
22 Dust rotary sluice lock
23 Primary air intake pipe
24 Primary air fan
25 Secondary air fan
26 Hydraulic unit
27 Concrete chimney
28 Garage
29 Slag ship

FIGURE R-3. CROSS SECTION OF BADEN-BRUGG PLANT
(Courtesy Widmer + Ernst)

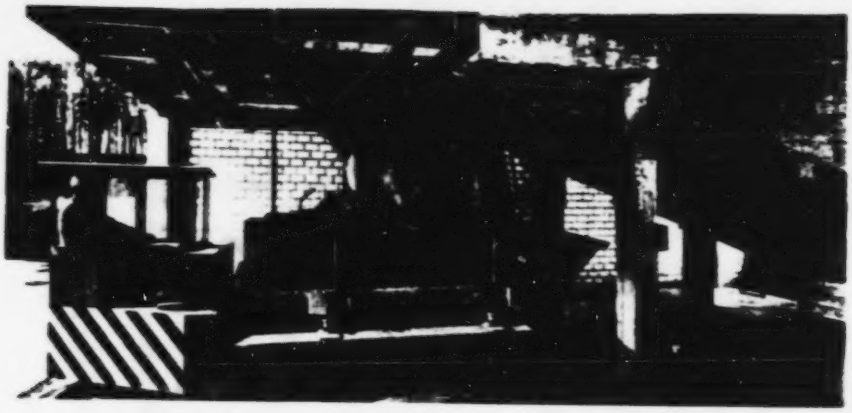


FIGURE R-4 DISCHARGE END OF RESIDUE CONVEYOR AT AARAU, SWITZERLAND SHOWING ELECTRIC TRUCK FOR REMOVING LOADED HOPPER (Courtesy of Widmer & Ernst)

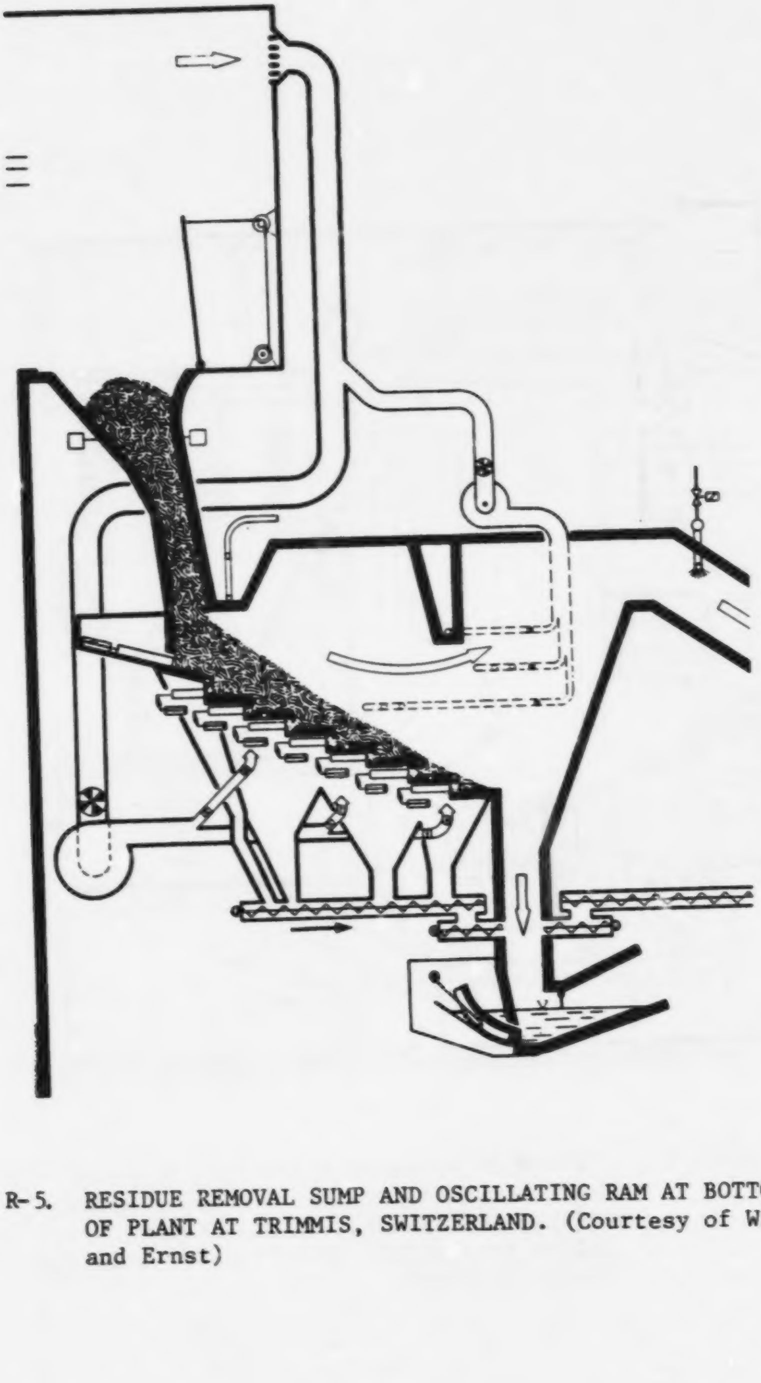


FIGURE R-5. RESIDUE REMOVAL SUMP AND OSCILLATING RAM AT BOTTOM OF PLANT AT TRIMMIS, SWITZERLAND. (Courtesy of Widmer and Ernst)

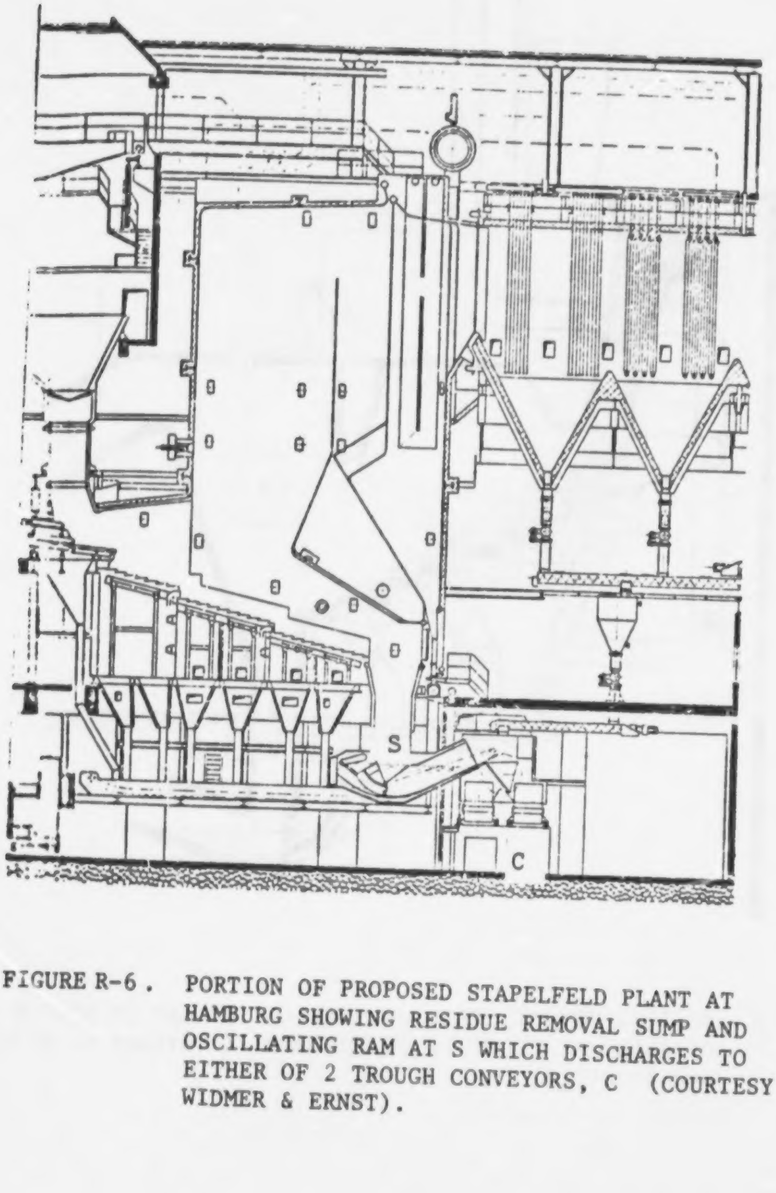


FIGURE R-6. PORTION OF PROPOSED STAPELFELD PLANT AT HAMBURG SHOWING RESIDUE REMOVAL SUMP AND OSCILLATING RAM AT S WHICH DISCHARGES TO EITHER OF 2 TROUGH CONVEYORS, C (COURTESY WIDMER & ERNST).

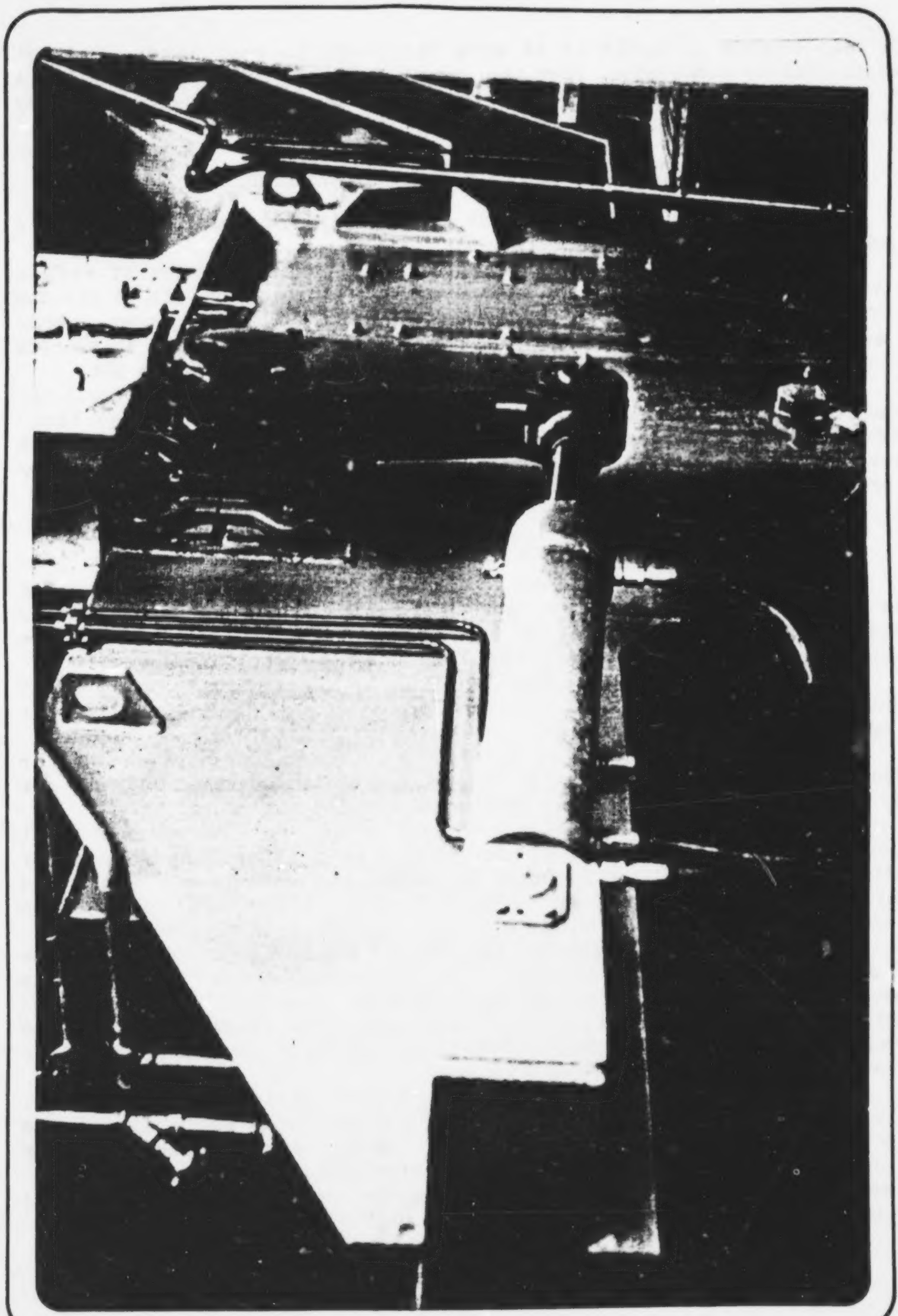


FIGURE R-7. WIDMER & ERNST QUENCH TANK AND RESIDUE REMOVAL DRIVE MECHANISM AT OBERTHURGAN, SWITZERLAND (BATTELLE PHOTO).

with this system although it is more difficult to cool large, red hot clinkers than by submersion. From the spray quench the cooled residue falls into a belt or trough conveyor. Figure R-8 shows such a system built by Bruun and Sorenson at Uppsala, Sweden.

Ash Handling In the Plant, General Comments

The plant ash handling flow is usually (1) parallel (2) reverse or (3) perpendicular to the flow of refuse.

The parallel flow system (Figure R-9a) keeps the flow of refuse and ash generally forward and downward until reaching the pit at the far end of the plant. The reverse flow system (Figure R-9b) , however, sends the ash back under the furnace back towards the refuse pit. At the VKW plants at Wuppertal and Krefeld, the refuse pit is next to the ash pit.

Thirdly, the perpendicular flow system (Figure R-9c) redirects the ash to the side of the plant. Usually all active furnaces disgorge their residue onto the same active conveyor. Most plants have two conveyors with a diverter to control flow. Redundency is necessary so that one conveyor pin break does not require shutting down all lines in the plant.

Ash Recovery, General Comments

Of the 15 plants studied, 9 have some form of ash recovery. Of these 9, two recover it in an enclosed building, six outdoors at the rear of the plant and one has distant outdoor recovery. Ash recovery is more likely to be performed at large plants near large metropolitan areas.

Of the 9 operations, four are run by the refuse burning plant owners. However, in five central European operations, private enterprise is active.

Ferrous scrap for remelting and sized aggregate ash for roadbuilding are the items of value from refuse combustion ash. Only in one case, was mention made of yanking obvious copper out for recycling.

There were no attempts to recover glass or aluminum in post processing operations at any of the 30 plants visited. The reason for ignoring glass and aluminum is both technical and economical. Glass and aluminum may fuse to or may be fused upon at the high combustion temperatures. Some of the aluminum may even vaporize into aluminum oxide.

Based on research done in Switzerland and Sweden there is definite road ash potential from processed ash. A normal refuse fired steam generator is a segregator of acids and bases. Normally the sulfur and chlorine rise and exit as gas. However, much goes into sulfate and ferrous chloride as deposits on tubes and into collectable flyash particulate matter.

What remains in the bottom ash is quite basic. A bottom ash will likely have a pH of 9 to 12 depending on refuse input composition. The basic nature causes the heavy metals to remain insoluble and relatively harmless to the environment. It is to be concluded that spreading basic bottom ash over an acidic soil to neutralize the resultant soil is not a good idea. Instead, the basic ash should be kept together as in a road base.

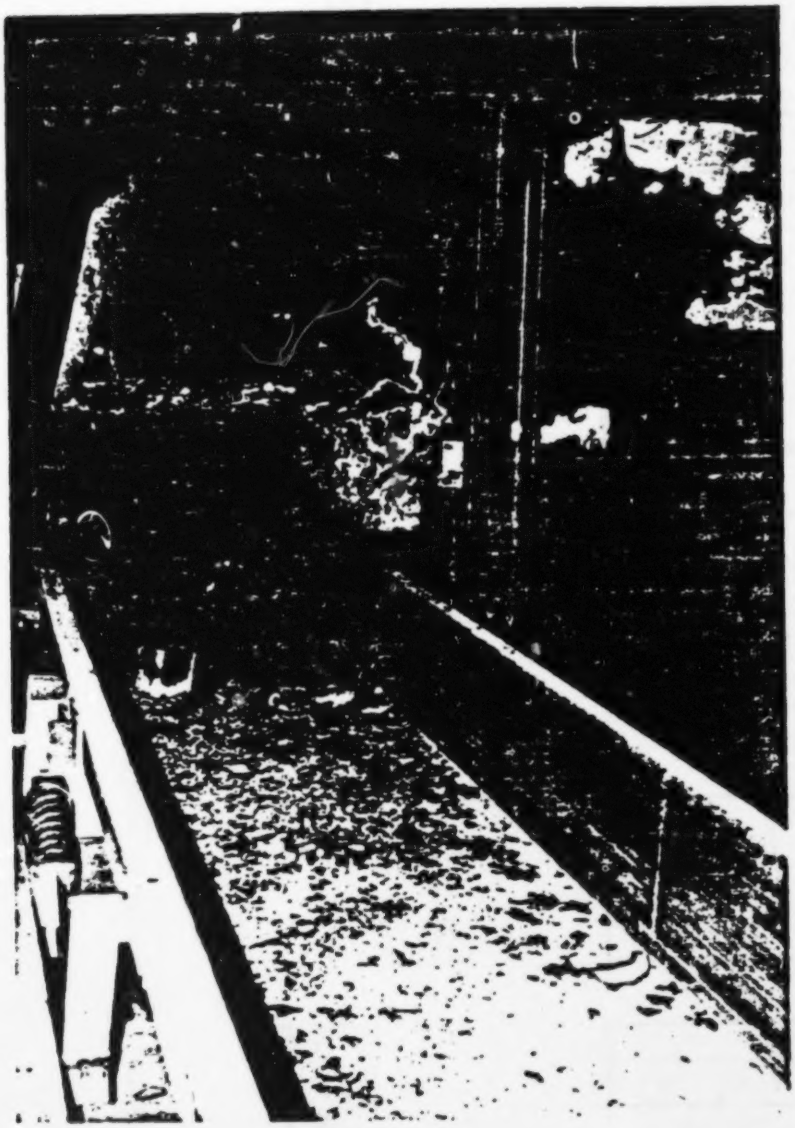
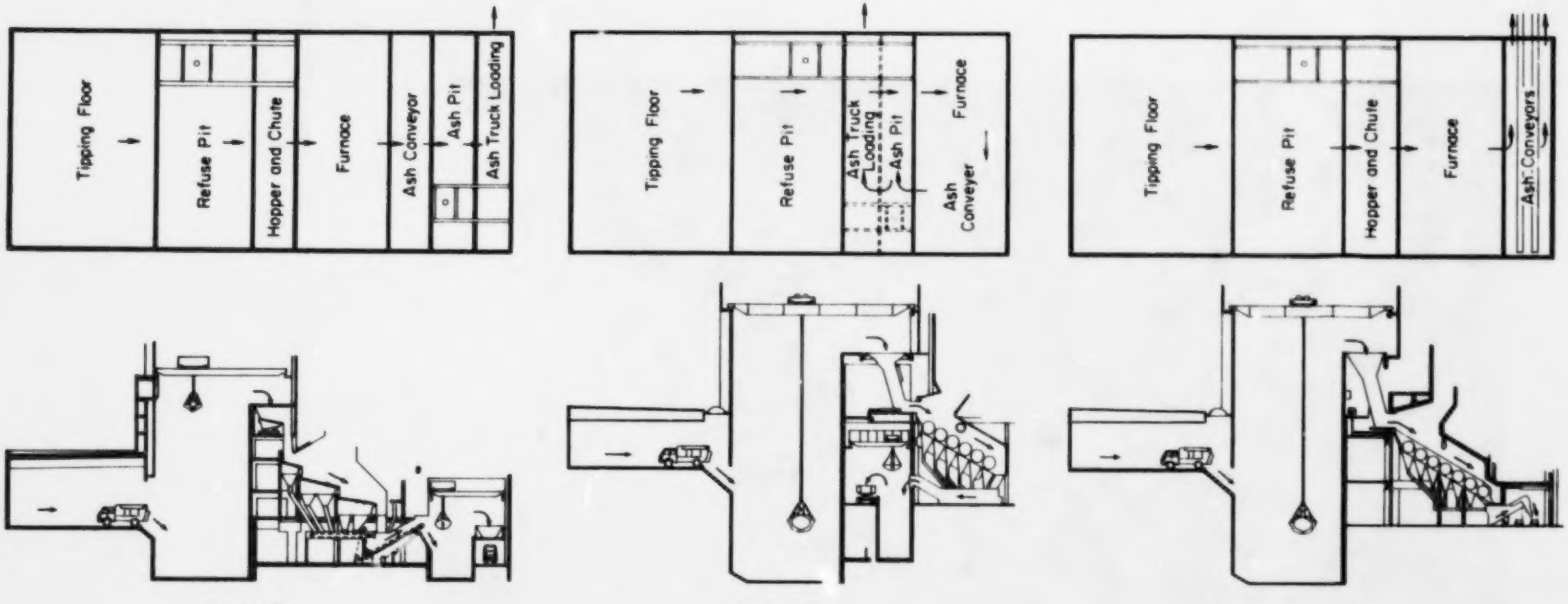


FIGURE R-8. FURNACE BOTTOM ASH CHUTE DISCHARGING INTO ASH VIBRATING STEEL CONVEYOR AT UPPSALA (Battelle Photograph)


Tipping Floor
Refuse Pit
Hopper and Chute
Furnace
Ash Conveyor
Ash Pit
Ash Truck Loading
Tipping Floor
Refuse Pit
Ash Truck Loading
Ash Pit
Furnace
Ash Conveyer
Tipping Floor
Refuse Pit
Hopper and Chute
Furnace
Ash Conveyors

Parallel Flow
(a)

Reverse Flow
(b)

Perpendicular Flow
(c)

FIGURE R-9. ALTERNATIVE DESIGNS FOR FLOW OF REFUSE AND ASH

Ash Handling and Recovery at Specific Plants

Werdenberg-Liechtenstein

Moist bottom and fly ash are dumped into a detachable container that is taken to a nearby hillside landfill. The tipping charge is about $.50 per ton. There is no attempt at any form of ash recovery.

Baden-Brugg

As at Werdenberg, the residue falls into a detachable container which is taken to a landfill.

Dusseldorf

A private operator processes ash at Duesseldorf inside a large building addition to the main refuse plant (See Figure R-10). The many conveyors, hoppers, magnets, sieves, etc., produce three separable products: (1) ferrous material, (2) road aggregate and (3) miscellaneous nonusable material for landfilling.

Figure R-11 shows two inclined conveyors removing baled scrap from the processing plant. Figure R-12 is a close-up of the baled scrap which, sold in 1975 for an average of 107.52 DM per tonne ($37/ton).

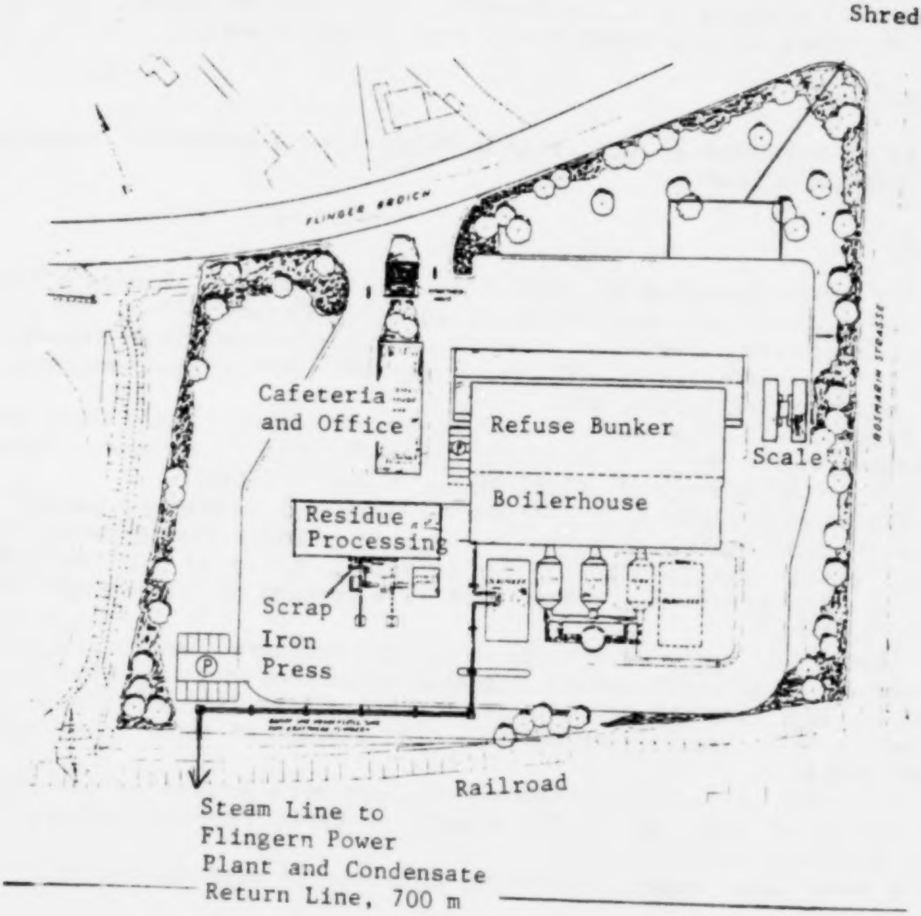
Figure R-13 pictures Mr. Thoemen, in lab coat answering questions of the visiting team while standing in the sized residue storage area. This fine gravel residue was sold in 1975 for an average price of 1.01 DM/tonne ($0.39/ton). The affiliated company sells a portion of the residue for 9 DM/tonne ($3.44/ton).

Because of refuse combustion and ash recovery, landfilling costs as a percent of total solid waste management costs (collection, transport, incineration and landfill costs) were only 143,375 DM ($54,682) for all of Duesseldorf in 1975. Landfilling was thus 0.43 percent of total solid waste management costs.

In 1975, 114,278 tonnes of raw ash were processed to obtain 105,092 tonnes of road ash, 5,986 tonnes of baled ferrous scrap. The remaining 3,192 was landfilled.

A later plant report describing 1976 results show the following:

Wet Residue	
Fine Ash for Roadbuilding	78,706.30 Tonnes
Discarded in Landfill	19,650.28 Tonnes
Total Residue	98,356.58 Tonnes
Total Residue Shipped	97,641.58 Tonnes
Storage (Net Increase in Stock)	935.00 Tonnes
Residue Analysis	
Water	18.89 Percent
Combustible	5.03 Percent
Scrap Iron	
Total	8,492.42 Tonnes
Bulky Scrap (non-baled white goods, etc.)	531.51 Tonnes


Shredder
FLINGER BROICH
ROSMARIN STRASSE
Cafeteria and Office
Refuse Bunker
Boilerhouse
Scale
Residue Processing
Scrap Iron Press
P
Railroad
Steam Line to Flingern Power Plant and Condensate Return Line, 700 m

Total Area:	30,831 sq. meters
Buildings:	7,000 sq. meters
Streets:	15,831 sq. meters
Trees, Shrubbery, Grass	8,000 sq. meters

FIGURE R-10. PLAN OF DUESSELDORF WASTE-TO-ENERGY PLANT (COURTESY STADTWERKE DUESSELDORF)

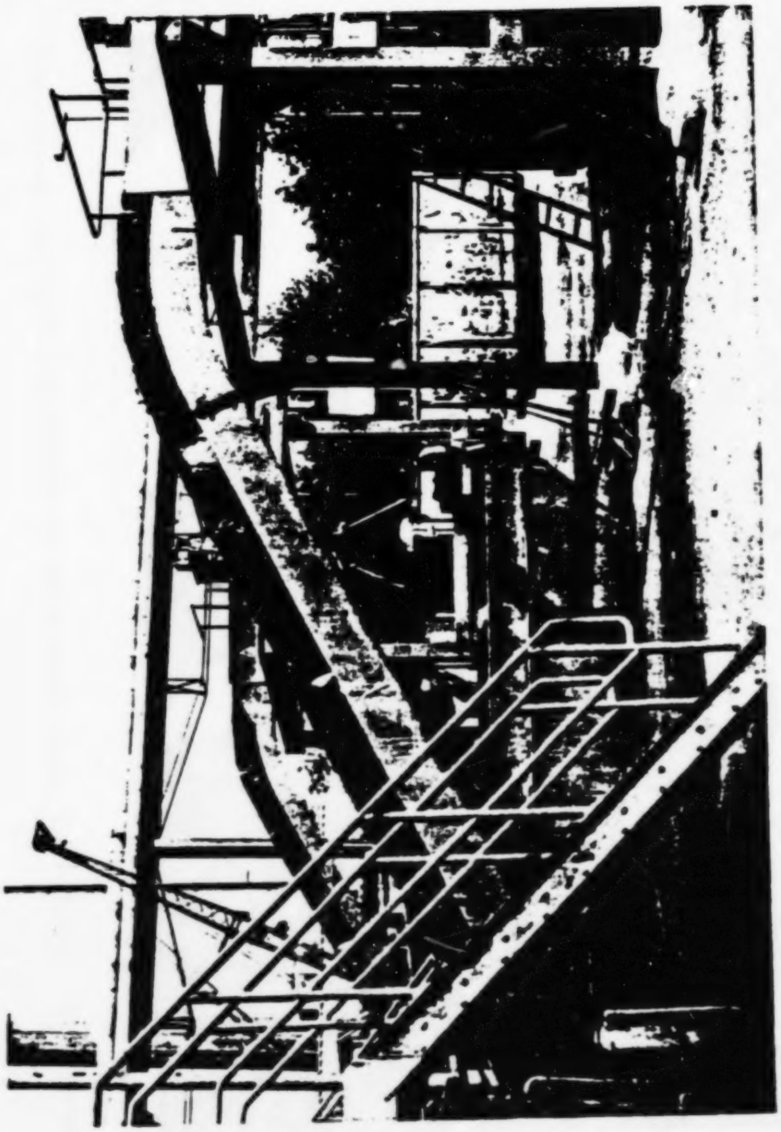


FIGURE R-11. INCLINED CONVEYORS REMOVING BALED SCRAP AT DUESSELDORF (Battelle Photograph)

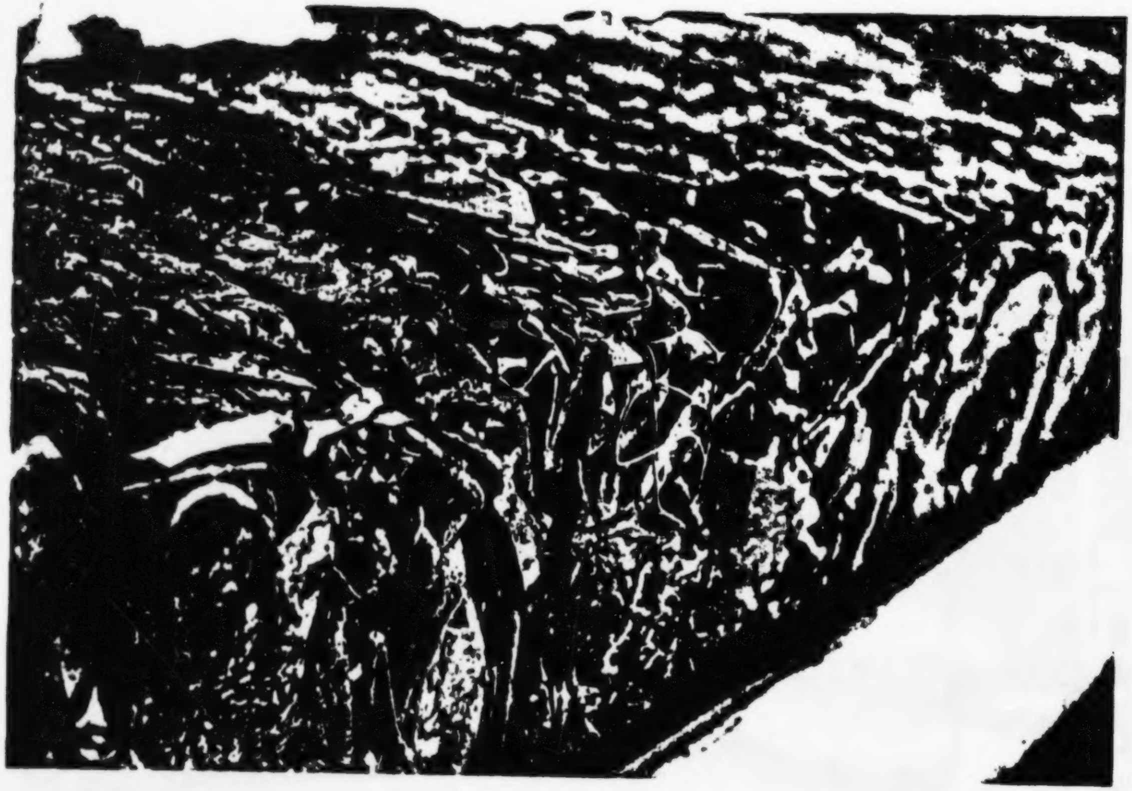


FIGURE R-12. COLOSE-UP OF BALED STEEL SCRAP AT DUESSELDORF (Battelle Photograph)

FIGURE R-13. VISITORS DISCUSSING FINE ASH RESIDUE USES NEAR STORAGE AREA AT DUESSELDORF (Battelle Photograph)

Wuppertal

Residue exits the furnace room basement and enters the long ash quench pit located under the boiler. The wet solids are removed by a drag-chain conveyor to the ash bunker. From there a crane lifts the residue to trucks which deliver them to a private processing firm immediately below the plant. Part of this operation is shown in Figure R-14. The private operator pays DM 1.50 per tonne ($0.60/ton) of residue. In this outdoor cleaning and sizing operation, the residue is upgraded to a useful raw material which apparently is in much demand.

Krefeld

The ash is removed to a privately operated ash recovery area. Aggregate is prepared and often barged away as far as the Netherlands.

Paris:Issy

Being an older system, ash recovery systems are not as extensive at Issy as at several other facilities. Figure R-15 shows the ash conveyor going to a ash recovery structure. Ferrous metals are removed and sold as scrap. The volume of scrap and other related numbers are shown in Table R-2. In 1976, of the 522,404 tonnes burned, 154,017 tonnes of ash or 29.4 percent were landfilled. Hence we conclude that at Issy, ash recovery is not extensively practiced.

Hamburg: Stellinger-Moor

The Hamburg plant uses the Martin system. In Hamburg, the Heidemann Company has a contract with S-M to process and remove all ash.

Mr. Siegfried Heidemann was stockpiling most of the production and waiting for the price of this material to rise. Mr. Arndt, the plant manager, pointed out that Hamburg's sea level position provides many markets for the ash material. Much of this plant's ash is shipped to Scandinavia and East Germany. Heidemann sells the raw residue for 4.50 DM ($1.80) per tonne. He sells the processed road material for about 12 - 15 DM ($4.80 - $6.00) per tonne. Scrap iron prices vary widely and no figure was given.

Three Heidemann men are needed during the day to run the equipment.

The following mass balance accounting was provided assuming 1000 refuse input tonnes:

C, H, O etc. rising through the chimney	640 tonnes
Scrap iron (large pieces collected in RFSG)	10 tonnes
Scrap iron (mediums and fines)	65 tonnes
Road material, including flyash (?)	250 tonnes
Residue to landfill (stumps, tires, large paper rolls)	35 tonnes
Total refuse input tonnes	1000 tonnes

Twice a week, a truck takes singed tree stumps, tires, etc. to the landfill.

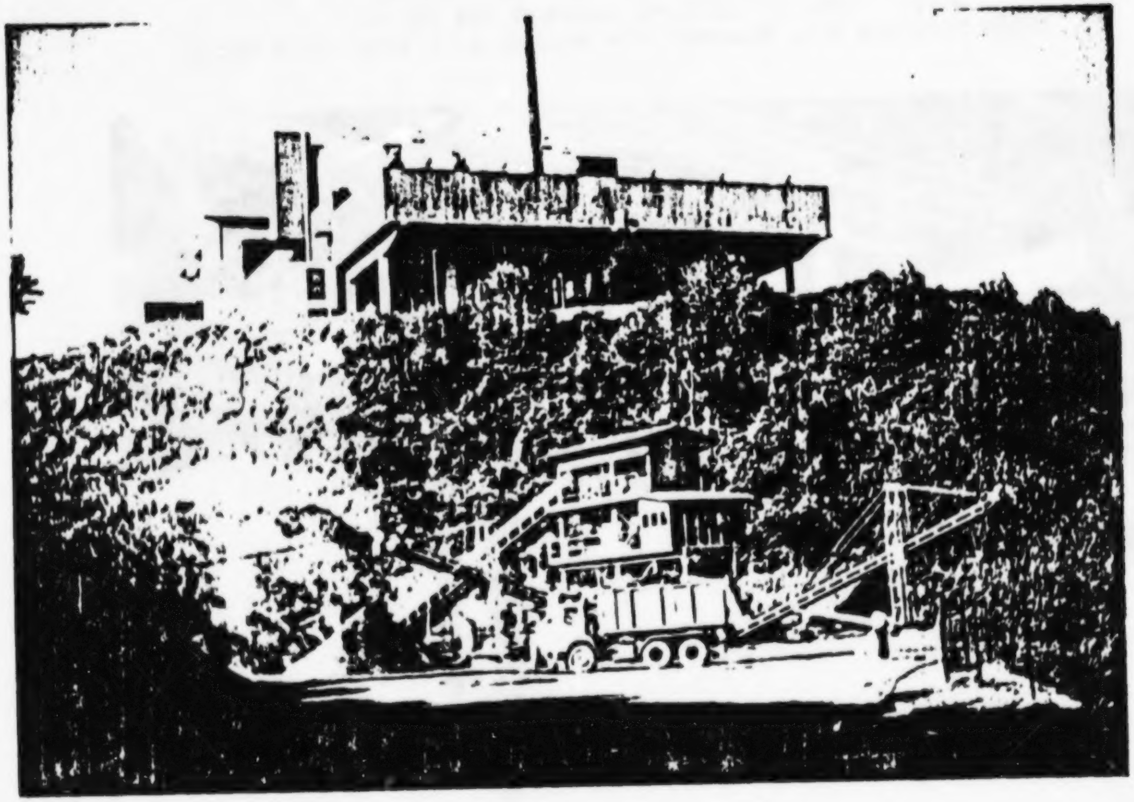


FIGURE R-14. WUPPERTAL PLANT SHOWING, IN TOP PORTION, THE AIR-COOLED STEAM CONDENSER HOUSING AT REAR OF PLANT AND BELOW THE PRIVATELY-OPERATED RESIDUE PROCESSING PLANT (Battelle Photograph)

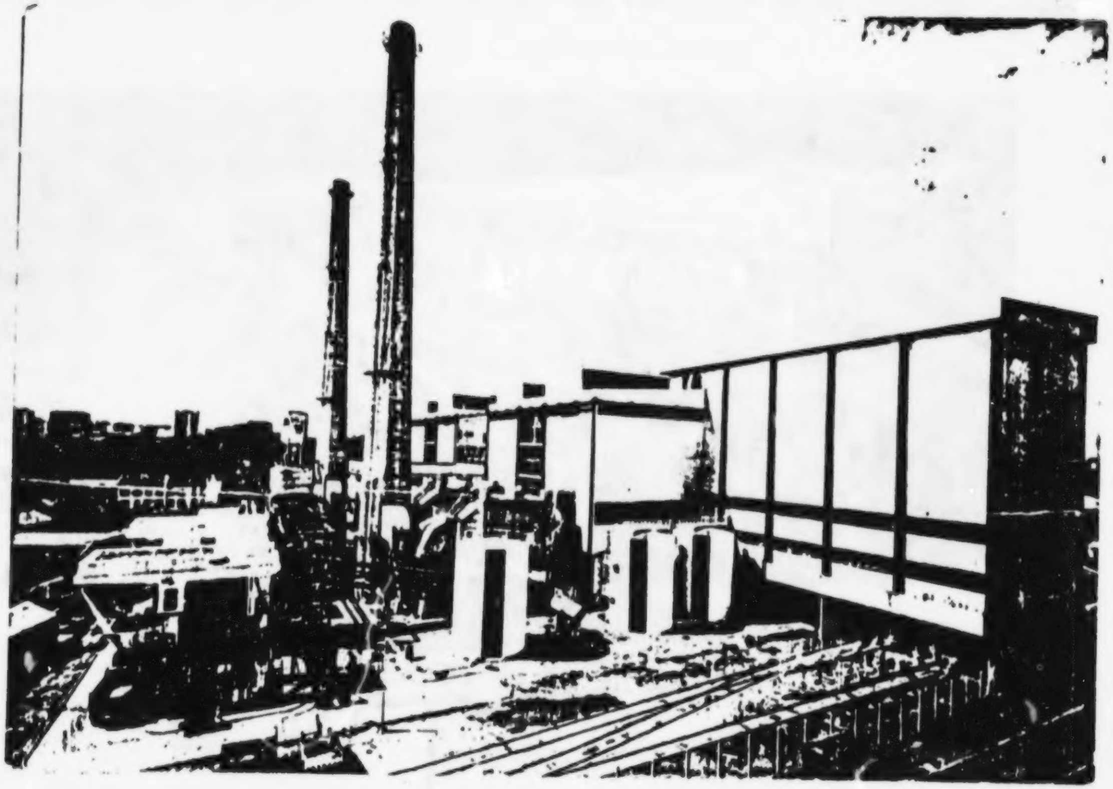


FIGURE R-15. REAR VIEW SHOWING ASH CONVEYOR FROM THE RFSG PLANT TO THE ASH RECOVERY FACILITY AT PARIS: ISSY (Courtesy of Josef Martin Feurungsbau, Gmbh)

TABLE R-2. DISPOSITION OF BOTTOM ASH, SCRAP METAL AND FLY ASH AT PARIS: ISSY

	Month of December		Year of	
	1976	1975	1976	1975
Tonnes of waste burned	53,426	48,206	522,404	521,046
Tonnes of scrap iron and bottom ash produced	18,699	16,872	205,679	198,664
Tonnes of fly ash produced	1,147	876	11,595	10,726
Percent scrap iron and bottom ash of total refuse input	34.5	35.0	39.4	38.1
Percent fly ash of total refuse input	2.1	1.8	2.2	2.1
Tonnes of bottom ash clinker sold	2,311	6,763	35,686	51,158
Tonnes of scrap iron sold	680	751	9,299	9.871
Percent sold as bottom ash clinker	4.3	14.0	6.8	9.8
Percent sold as scrap iron	1.3	1.6	1.8	1.9
Tonnes of bottom ash landfilled	17,504	9,525	154,017	138,352
Tonnes of bottom ash sent to Ivry			7,257	
Tonnes of fly ash landfilled	1,147	876	11,595	10,726
Percent bottom ash landfilled	32.8	19.8	30.9*	26.6
Percent fly ash landfilled	2.1	1.8	2.2	2.1

* Includes 1976 bottom ash sent to Ivry for metal recovery.

Source: TIRU statistics

Zurich: Hagenholz

Zurich: Hagenholz uses the Martin ash handling system described under Paris: Issy.

Fly Ash. To prevent blowing dust from fly ash, it needs to be wetted. While this is most difficult in the summer, wetting is almost impossible in the winter due to freezing. As a result, the screw conveyors transport all fly ash to the ash discharger where it is inserted 1 m (3 feet) above the water level. Some dust is recycled through the furnace/boiler/ESP but that is no real problem. The fly ash is later recycled for roadbuilding.

Ash Recovery. Ash recovery is very advanced at Hagenholz. Credit for this accomplishment is to be shared among several parties that have funded and guided the research and development. The entire program is outlined in an excellent 50-page report written by Professor R. Hirt, a professor of forest engineering at the Technical University in Zurich. His publication is titled, "Die Verwendung von Kehvichtschlacke als Baustoff fuer den Strassenban", dated October, 1975. The German title translated is "Use of Processed Incinerator Ash for Road Building". The report is available through Mr. Hirt.

The analysis mentions many Swiss cities. Data for the City of Zurich in 1974 are presented in Table R-3.

TABLE R-3 POPULATION, REFUSE AND ASH IN AND AROUND ZURICH

	City of Zurich	Zurich Metroplitan Area (14 Cities)	
Population	421,650	2,314,100	people
Refuse (generated, burned?)	216,000	812,285	tonnes/year
Refuse per person (kg basis)	512	351	kg/person/year
Refuse per person (pounds basis)	1,126	772	pounds/person/year
Refuse per person (365 days basis)	3.08	2.12	pounds/per day
Ash generated by incinerators*	61,800	271,260	tonnes/year
Ash per person (kg basis)	147	117	kg/person/year
Ash per person (pounds basis)	323	257	pounds/person/year
Ash per person (365 days basis)	0.88	0.70	pounds/person/day
Ash as percentage of Refuse	28.6	33.4	tonnes/tonnes

*Josefstrasse and Hagenholz both in 1974.

The ash disposal procedure is shown in Figures R-16 through R-23 and is outlined below.

Figures

R-16	Truck takes ash from plant and dumps on storage pile. Ash stays in pile for 2 weeks.
R-17	Front end loader has deposited bulky non-burning items (logs, tires, etc.) in bulky waste pile.
R-18	Front end loader takes ash from pile and dumps into first hopper.
R-19	Worker needs to remove wires and other jamming objects from the hoppers, conveyors, and vibration equipment.
R-20	Ferrous fines are separated.
R-21	Coarse ferrous is separated. (Some larger ferrous is separated where the ash discharger dumps into the incineration plant's ash vibrator.
R-22	Nonferrous small material less than 1 cm (.39 in.) is stockpiled for later use as road bed subsurface material.
R-23	A test patch is shown.

The ash residue (slag), when removed from the ash bunker, is stored in a pile for two months for these several reasons:

- moisture reduction
- stop fires
- chemical reactions desired
  - heat of hydration of free lime
  - water and calcium carbonate

These exothermic reactions result in an internal temperature of 80 C (176 F). The bottom ash and flyash combined residue has a pH of 11 or 12. Interestingly, the dirty water removed during the semiannual boiler cleaning to remove flyash deposits has a pH of 2 or 3 despite use of an alkaline cleaning agent. Incinerators segregate acids and bases. Flyash removed from the precipitators is always basic.

In 1976, the actual following figures were reported:

Quantity of solid waste burned	218,342 tonnes	100.0 percent
Quantity of raw ash generated	56,271 tonnes	25.8 percent
Quantity of metal recovered	6,494 tonnes	3 to 5 percent

The following are percentage ranges for output from the ash recovery process:

Roadbuilding material	80 percent
Ferrous metals	8-9 percent
Non-ferrous mediums returned to furnace	3-5 percent
Stumps and tires sent to landfill	3-5 percent

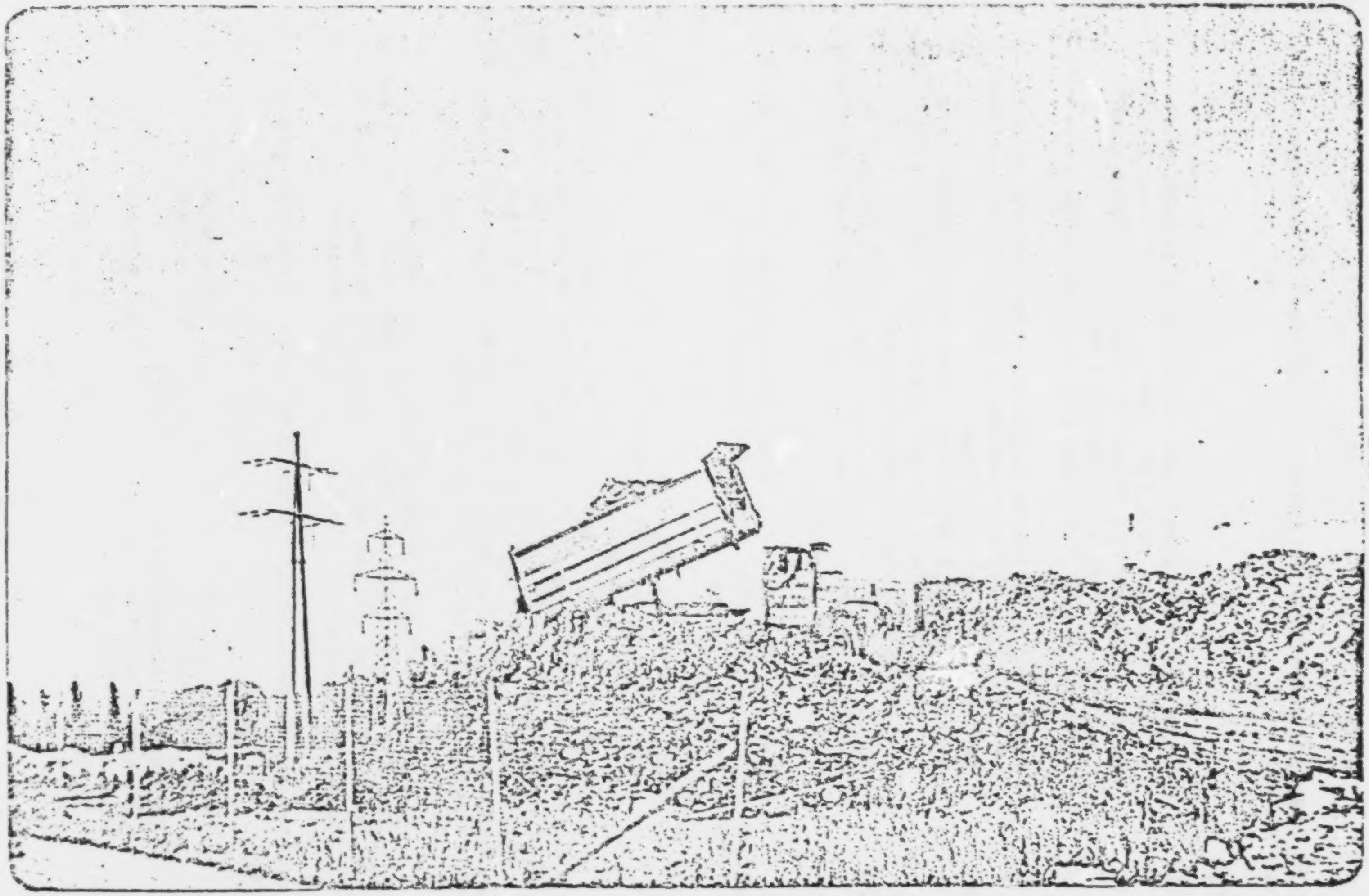


FIGURE R-16. TRUCK DUMPING UNPROCESSED AHS (FOR TWO-WEEK STABILAZATION PRIOR TO PROCESSING) AT ZURICH: HAGENHOLZ

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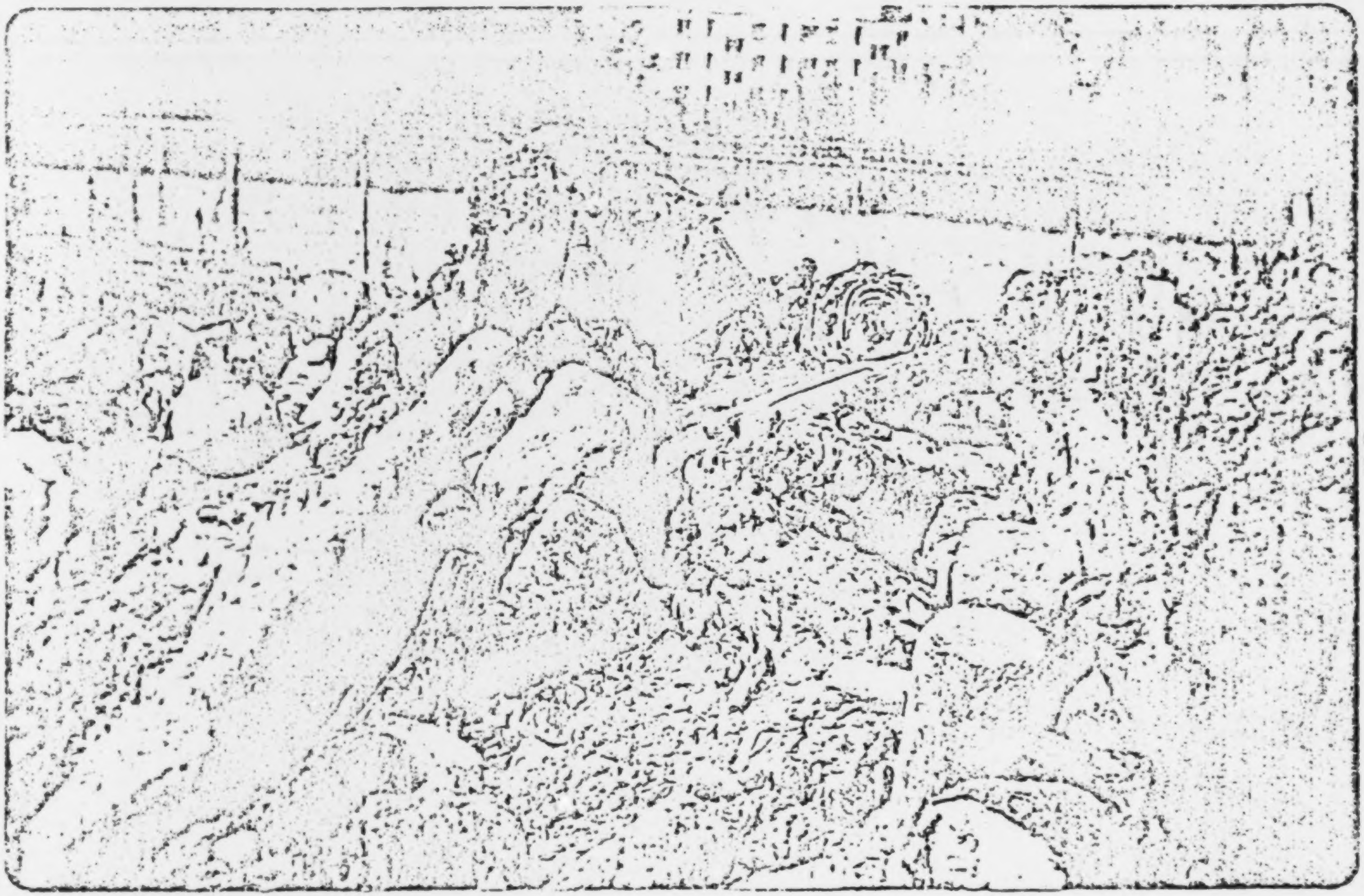

FIGURE R-17. SINGED STUMPS, TIRES, PAPER ROLLS, ETC., REMAINING AFTER ASH PROCESSING AT ZURICH: HAGENHOLZ

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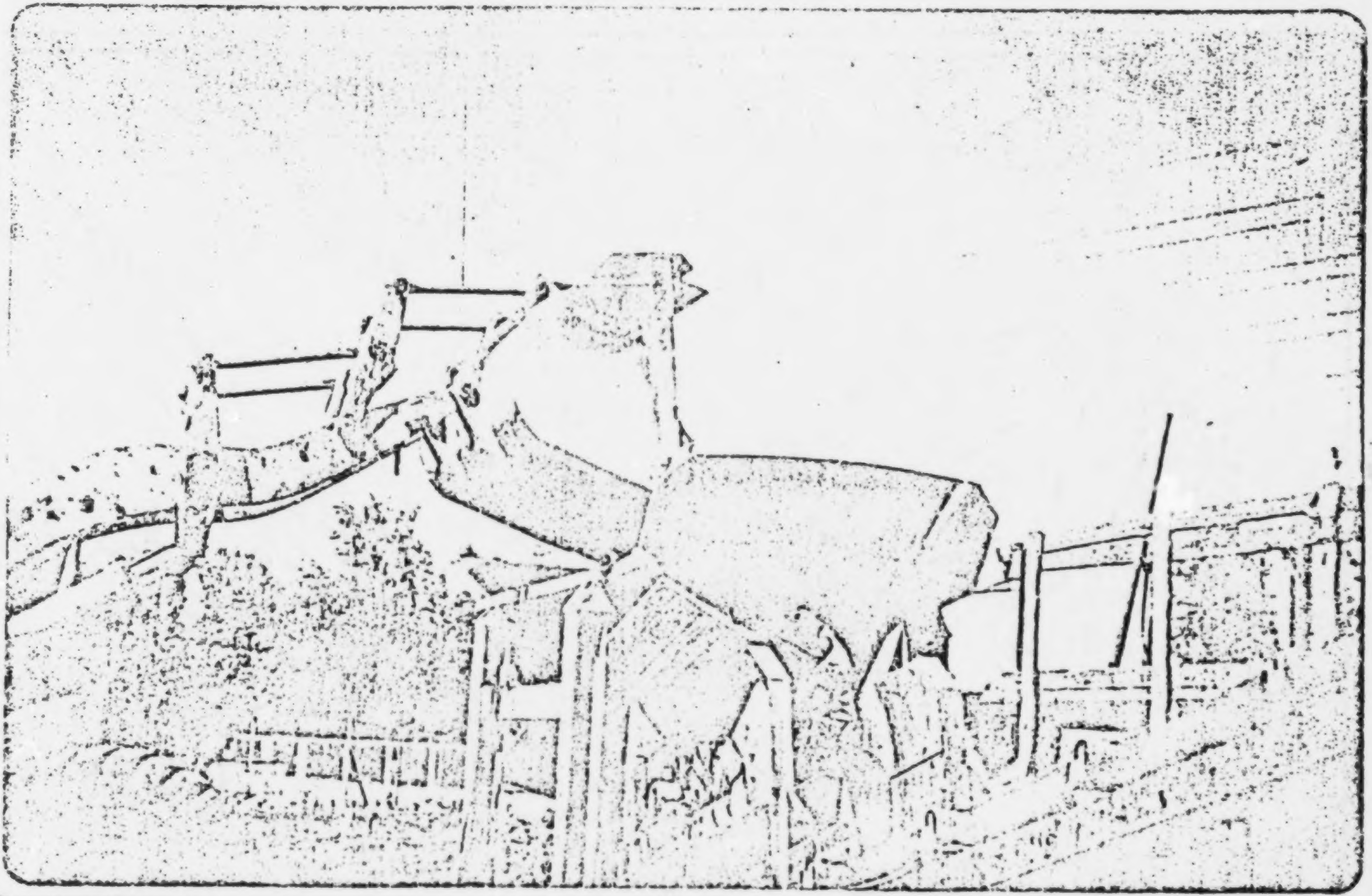

FIGURE R-18. FRONT END LOADER DUMPING ASH INTO BEGINING OF ASH PROCESSING SYSTEM (HOPPER, VIBRATING CONVEYOR AND RUBBER BELT CONVEYOR) AT ZURICH: HAGENHOLZ

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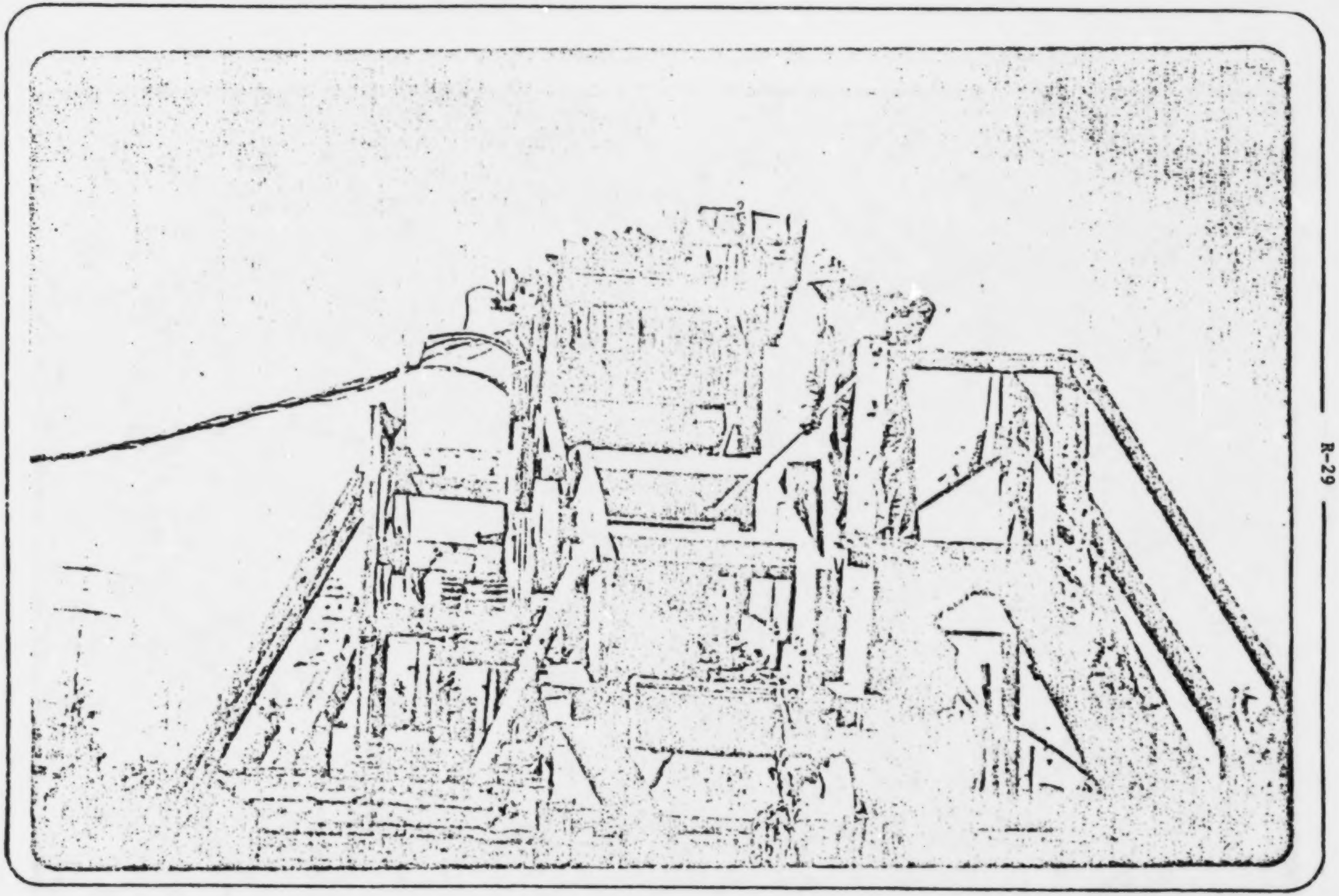

FIGURE R-19. WORKMAN REMOVING JAMMED MATERIAL FROM VIBRATING CONVEYOR NEAR END OF COARSE FERROUS LINE AT ZURICH: HAGENHOLZ

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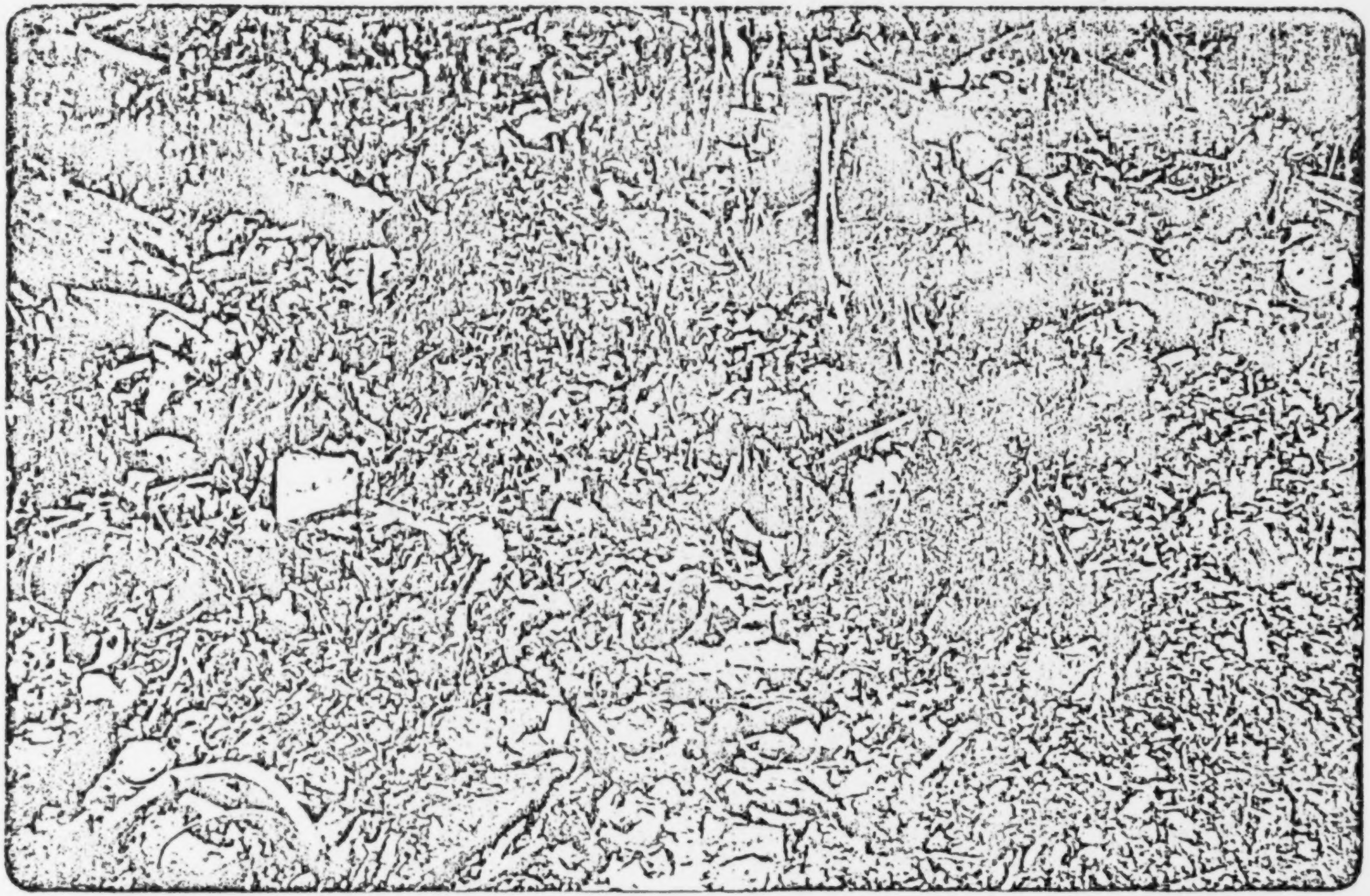

FIGURE R-20. MEDIUM FERROUS SCRAP FROM THE ASH RECOVERY PROCESS AT ZURICH: HAGENHOLZ

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FIGURE R-21. COARSE FERROUS SCRAP FROM THE ASH RECOVERY PROCESS AT ZURICH: HAGENHOLZ

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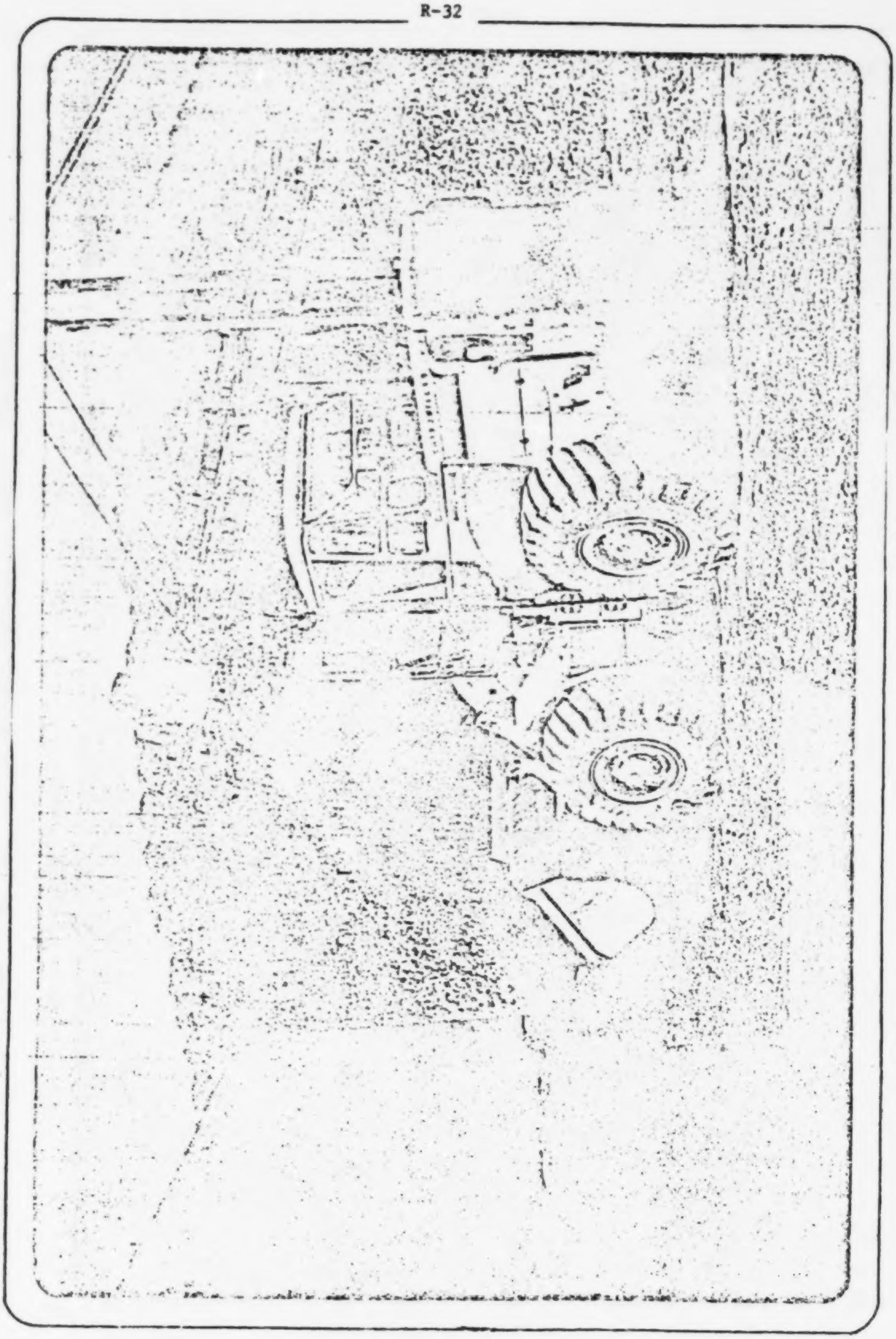

FIGURE R-22. MOUNTAIN PILE OF PROCESSED AHS (1/4" AND LESS) FOR ROAD BUILDING AT ZURICH: HAGENHOLZ

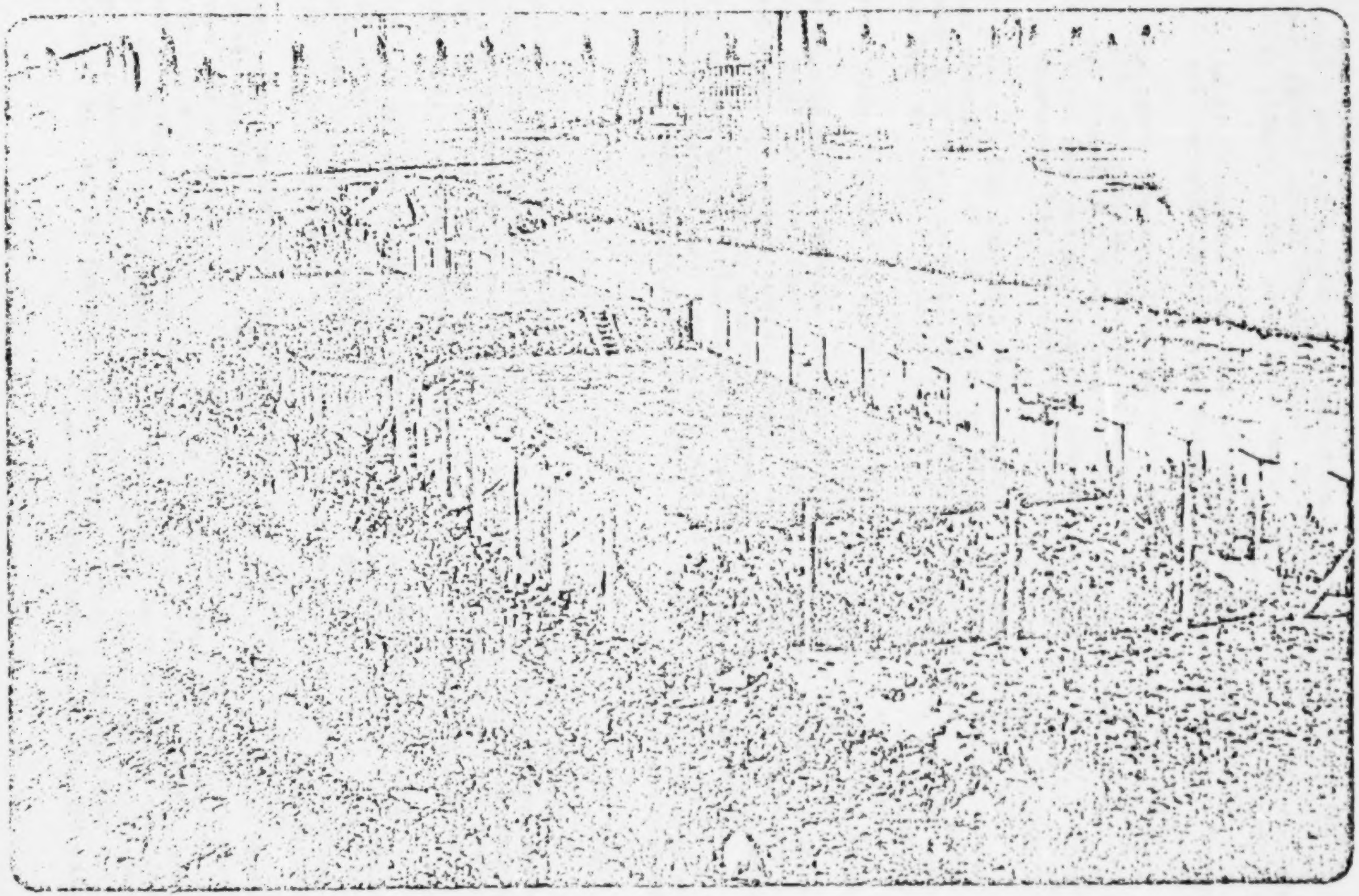

FIGURE R-23. EXPERIMENT ROAD PATCH TO TEST HEAVY METAL LEACHING OF PROCESSED ASH USE

Except for uncaptured particulates and gases, the only materials not recycled are the tree stumps and tires. This amounts to 3 to 5 percent of ash; and ash is 25.8 percent of the total waste input. This means that there is a 98.75 to 99.25 percent volume reduction, which greatly reduces the necessary landfill requirements.

The copper,when conveniently seen and removable, is manually removed and sold is as scrap. Aluminum is recycled indefinitely until oxidized.

In 1974, before the recession, ferrous incinerator scrap sold for 30-90 S.Fr. ($12-35) per tonne depending on market conditions. In 1977, the price ranged from 30-55 S.Fr. ($15-17) per tonne F.O.B. Zurich. Note the singular effect of the exchange rate and the devaluing American dollar. For example: 30 S.Fr. in 1974 equals about $12 while the 1977 conversion of 30 S.Fr. is about $15.

The roadbuilding ash (or slag as most Europeans call it) sells for 10 percent under the competitive price for gravel. Mr. Hirt believes that the long term price is bound to rise substantially as gravel pits become scarce. The 1974 price of S.Fr. 12 S.Fr. had fallen to 6 S.Fr. in 1977 due to the recession.

There is a new plan to mix the material as aggregate with cement to serve the Zurich and Wintertur areas.

Most of the processed ash is used for secondary roads.Because the material can also be used as road base for paved roads, several tests have been conducted. Tubes made of PVC, cement, zinc, rubber, etc. have been inbedded in the processed ash to determine corrosion effects.

Three people, not employees of Abfuhrwesen, operate the facility for a joint venture owned by the Bless and the Muldenzentrale companies.They can operate in rain and freezing weather due to the exothermic reactions.

The Hague

The ash handling process at The Hague is noteworthy due to separate treatment of bottom and flyash. Figure R-24 shows the total plant arrangement. Bottom ash that has been water sprayed at the furnace exit is conveyed to the first pit. Flyash is slurried as it leaves the electrostatic precipitator hopper. The flyash slurry is piped to the second bunker.

Clam shell buckets as shown in Figure R-25 remove the ash from the tanks and drop it onto a large mesh grate set at an inclined angle. The larger material rolls down to a detachable container. The smaller material falls through onto a conveyor belt that is the beginning of an ash separation plant.

Until very recently, the quenched furnace residue and wet flyash have been hauled by rail to the Rijswijk landfill without any processing for resource recovery. However, in August 1977 the processing equipment shown in Figure R-26 was installed adjacent to the plant by a private company which evidently hopes to benefit from ash recovery. The magnetically separated steel scrap piled in the foreground is to be sent to a steel plant. The conical pile of sized cinders in the back ground will be used for fill and road building. This processing plant is too new to have produced any data on its costs and revenues.

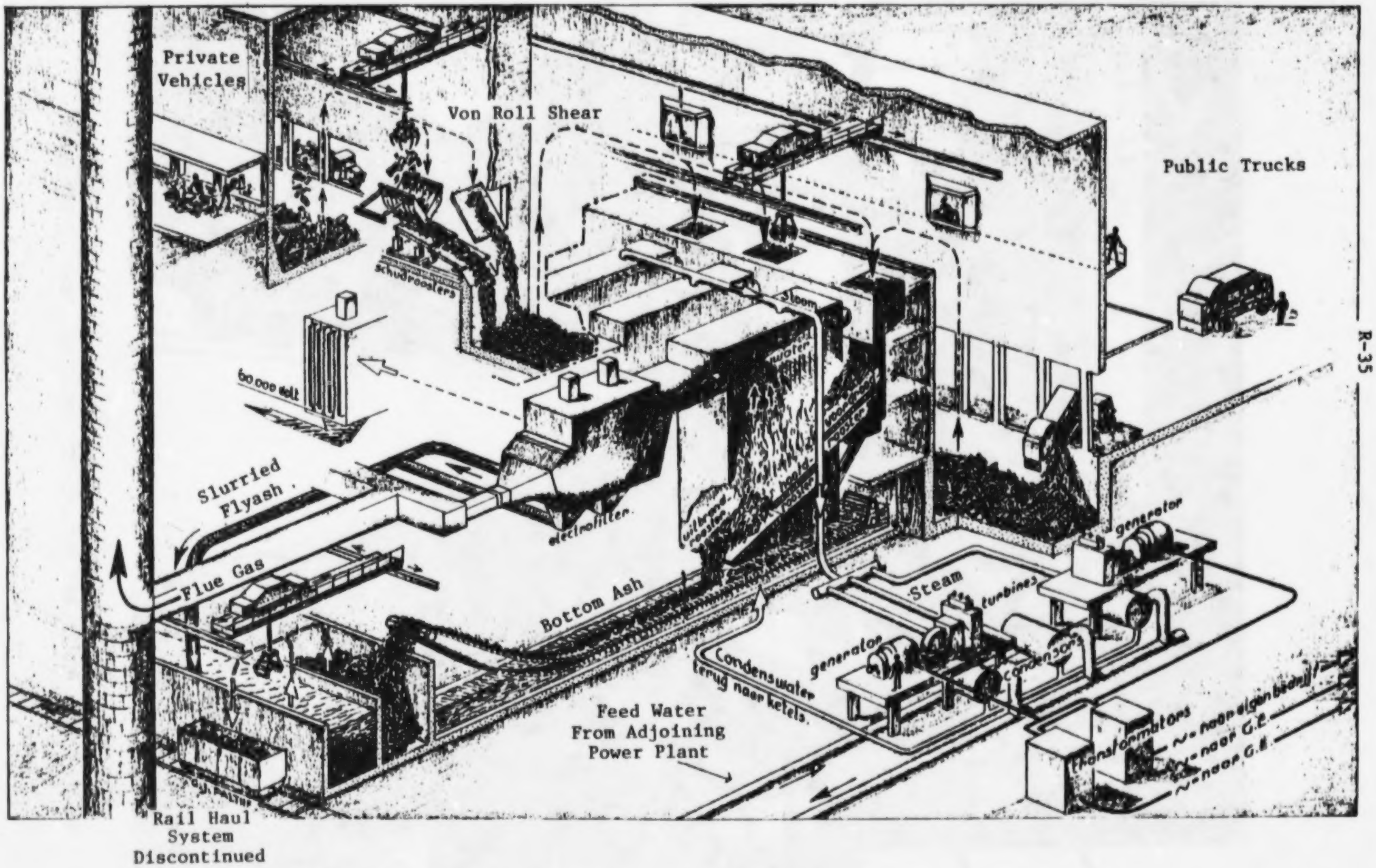
Private Vehicles
Von Roll Shear
Public Trucks
schudroosters
60 000 volt
stoom
water
electrofilter
Slurried Flyash
Flue Gas
Bottom Ash
Steam
turbines
generator
generator
condensor
Condenswater terug naar ketels.
transformators
~ naar eigen bedrijf
~ naar G.E.
~ naar G.E.
Feed Water From Adjoining Power Plant
Rail Haul System Discontinued

FIGURE R-24. SKETCH OF THE HAGUE PLANT HIGHLIGHTING THE BOTTOM ASH PIT AND THE FLYASH SLURRY TANK (Before Ash Recovery Was Installed)

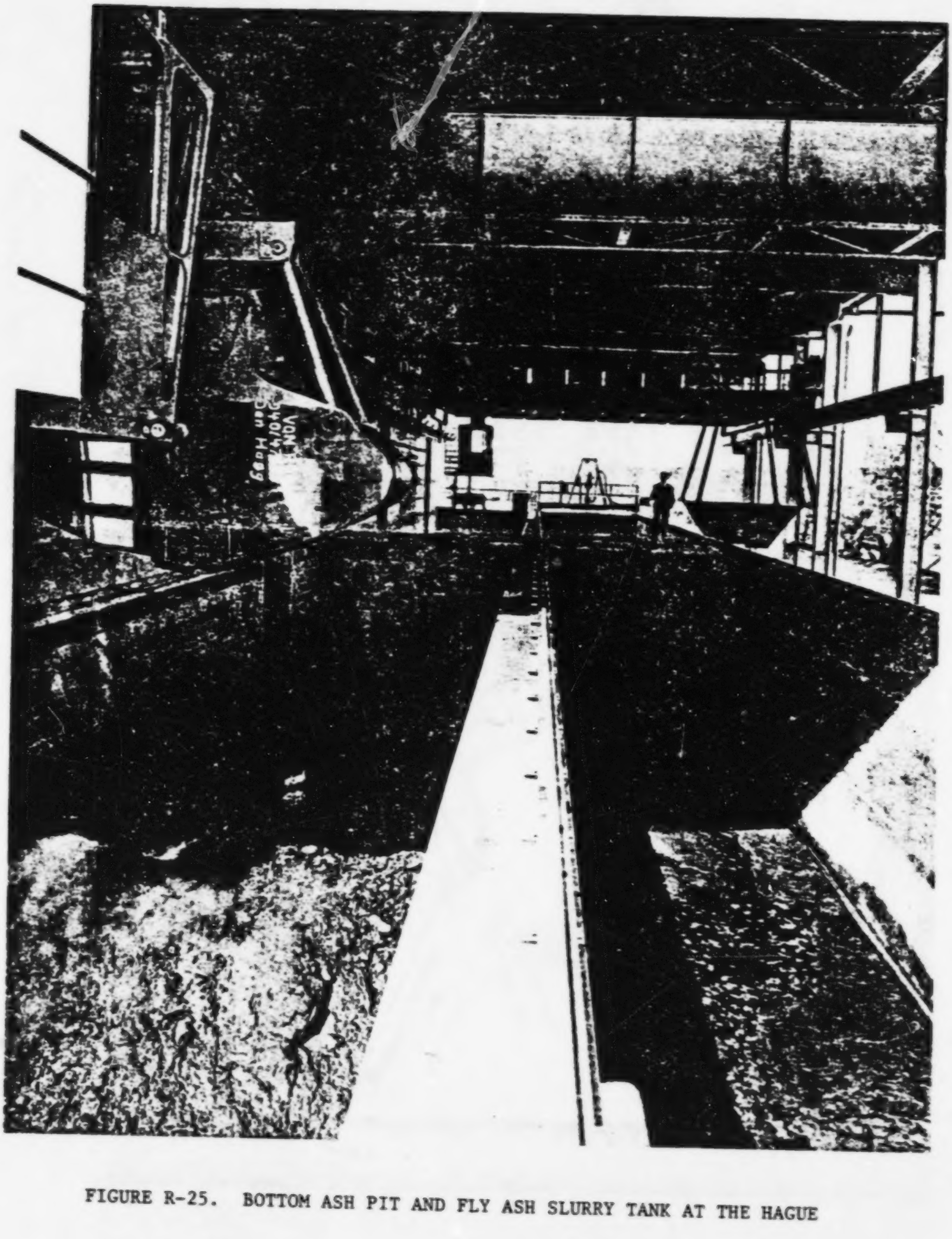

FIGURE R-25. BOTTOM ASH PIT AND FLY ASH SLURRY TANK AT THE HAGUE

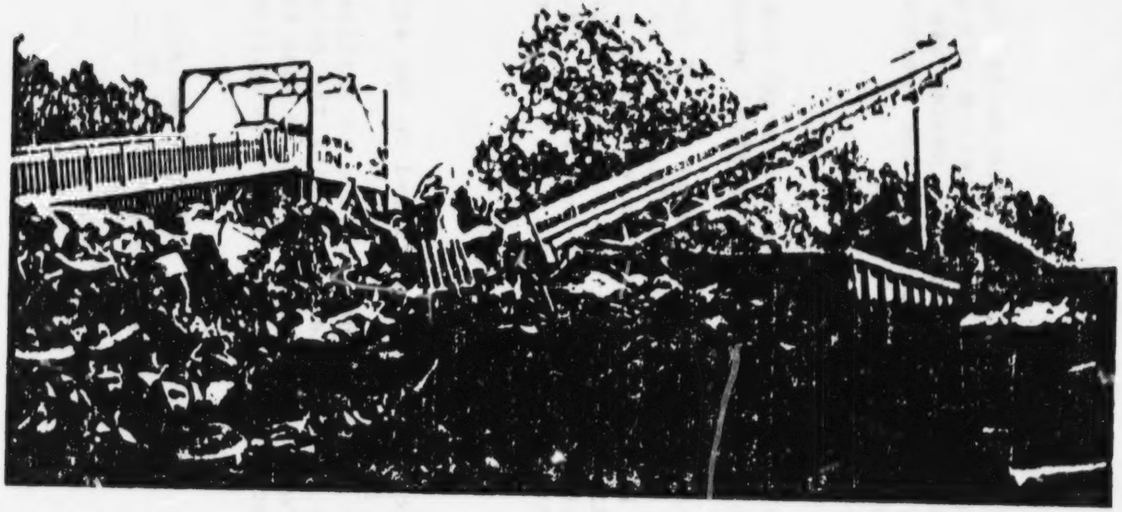

FIGURE R-26. CONVEYORS AND MAGNETICALLY SEPARATED SCRAP AND PILE OF SIZED RESIDUE ACCUMULATED BY NEW RESOURCE RECOVERY SYSTEM ADJACENT TO THE HAGUE PLANT (Battelle Photograph)

Dieppe

Ash at Dieppe is taken to an area on the same property where it is dumped. Since the property is not located in residential area, there are few complaints.

Gothenburg

The new Tagene landfill which receives the residue has a clay base from which drainage (leachate) is collected and piped to the local wastewater treatment plant. When the system was planned, there were tentative plans for metal recovery from the residue. The planned metal recovery has not been implemented to date.

Uppsala

Figure R-27 shows ash being discharged from the furnace and onto the vibrating conveyor. Note the glowing steel because quenching is not performed.

Figure R-28 shows the discharge end of the vibrating conveyor. Detachable residue containers on rollers are used to collect residue for later trucking to Hovgarden. The ash conveyor is at ground level. A shallow elevator pit operating from ground level to one position below lowers and raises the container for filling and removal. (See Figure R-29).

The quenched residue is hauled 4.4 km (7 mi) to the Hovgarden landfill.

Horsens

The quenched residue is hauled to the adjacent landfill in a dammed area of the fjord.

A sample of the burned residue is analyzed daily by the city laboratory for combustible content by heating the dried residue in air to 600 C (1,112 F) for a long enough time to oxidize the combustible matter. The following are some typical values of combustible content of the dry solids in percent:

Day Sampled	Week of Analysis (1977) July 5	Aug. 10	Sept. 15
Monday	3.1	3.8	4.0
Tuesday	0.8	2.4	1.8
Wednesday	1.6	3.0	2.4
Thursday	2.0	5.6	3.5
Friday	3.2	2.9	2.0

FIGURE R-27. ASH BEING DISCHARED FROM FURNACE ONTO VIBRATING STEEL CONVEYOR AT UPPSALA

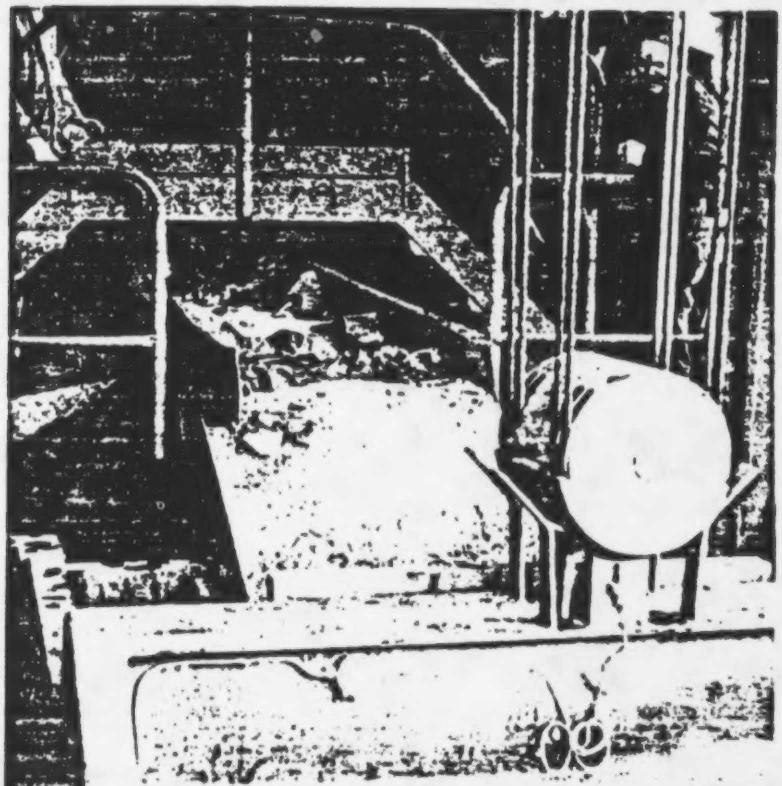

FIGURE R-28. VIBRATING STEEL CONVEYOR DUMPING BOTTOM AND FLY ASH INTO CONTAINER AT UPPSALA (Battelle Photograph)

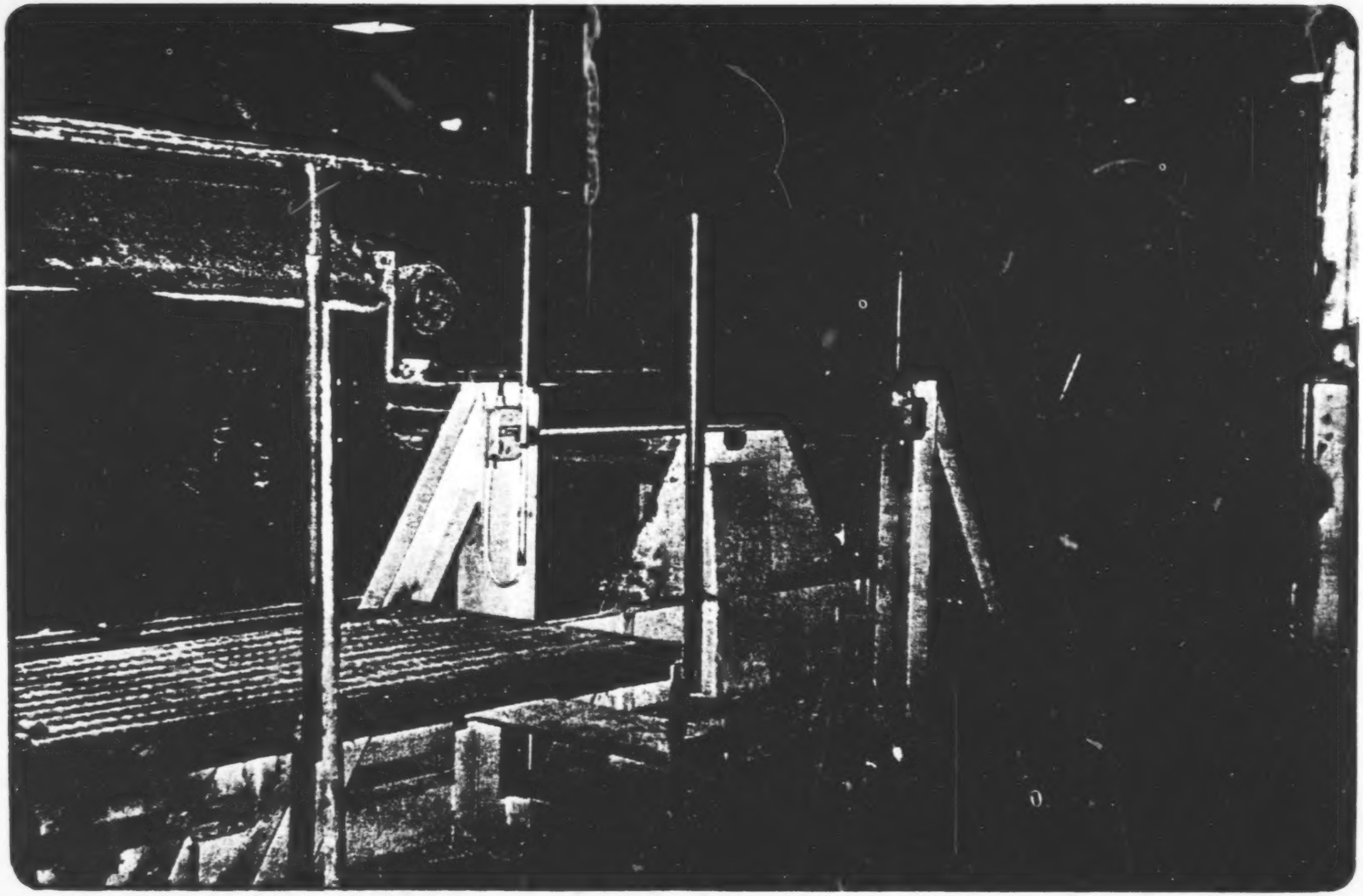

FIGURE R-29. ELEVATOR FOR ASH CONTAINERS IN PIT ONE LEVEL LOWER THAN ASH CONVEYOR AT UPPSALA

These results indicate consistently good burnout. The plant specification called for a value of 5 percent combustible. A daily check on the trend of this number is a useful clue to the general performance of the furnace. As in all analyses of heterogeneous materials, the size of sample and mode of sample can be critical in producing useful numbers. An occasional duplicate sample for the same day would be helpful in assessing the data variability.

Copenhagen: Amager

Unfortunately, the ash handling system at Amager caused considerable problems. Based on Amager's experiences, West was redesigned and operates much better. Basically, Amager uses conveyors while West uses a skip hoist.

Originally the Amager rubber ash conveyors let too much water and fine ash into the tank bottom. The material would settle, buildup, and then interfere with the conveying. There was excessive wear on rollers and nylon bearings. Downtime for repair and fines removal was excessive.

To partially solve the problem, apron conveyors were replaced by vibrating conveyors. They have also installed air pipes in the bottom of the fines tank to keep the siftings in solution so they can be removed.

Another major difference is that Amager uses about 3 tonnes of water per tonne of ash while West uses only 1 tonne of water per tonne of ash. Boiler blowdown water is used.

Ash disposal at Amager is entirely different from the treatment at West. The Amager ash is dropped into a hopper which feeds a conveyor as seen in Figure R-30a. Ferrous material is extracted just before loading the ash into the truck. The ash is then trucked (Figure R-30b) to reclaim further portions of Amager Island. It is very profitable in that 1 m^2 (1 yd^2) of land reclaimed from the sea is worth 200 to 300 Dkr ($35-52). About 3 m^3 (4 yd^3) volume of ash is used to reclaim a 1 m^2 (1 yd^2) area. This converts to a land value of $188,000 to $280,000 per acre.

Copenhagen: West

The subject of "ash" at West is discussed in two major parts. This part on ash handling and processing discusses matters at the West plant itself. The later part on ash recovery discusses physical and chemical properties of processed ash as a usable gravel material. This following part also discusses the encouraging environmental story of ash percolate (leachate).

Ash Handling. The authors wish to thank Mssrs. Balstrup and Pedersen for material included. West's experiences have been much better than those of Amager. In contrast to Amager's rubber belt conveyors, West uses a skip hoist as shown in the dump position in Figure R-31.
Also to be noted are the two flapper doors (swivel gates) that control in-plant ash atmospheres to minimize dust and noise. When the hoist is traveling or dumping, the bottom door is closed while the top door is open. Ash thus accumulates in the ash chute. When the hoist returns and the chute has filled, the top door is closed and the bottom door is opened to allow the ash to fall into the hoist.

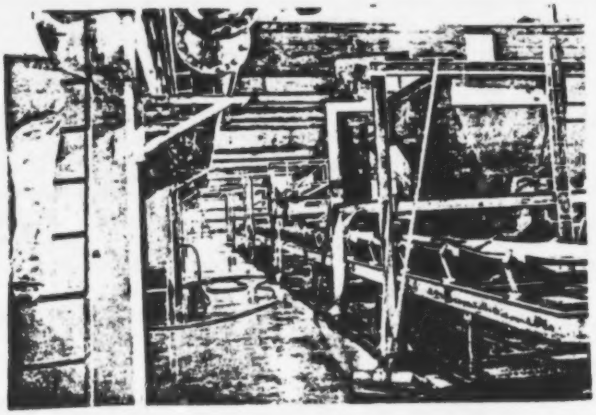

FIGURE R-30a. RUBBER ASH CONVEYOR AT COPENHAGEN: AMAGER

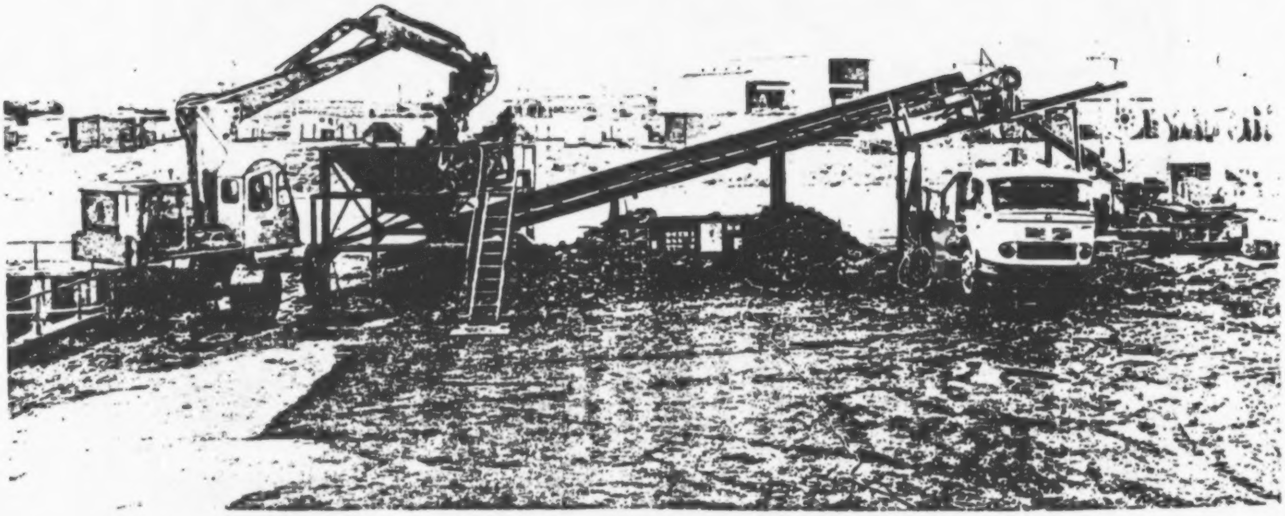

FIGURE R-30b. FERROUS SEPARATION FROM ASH AT COPENHAGEN: AMAGER

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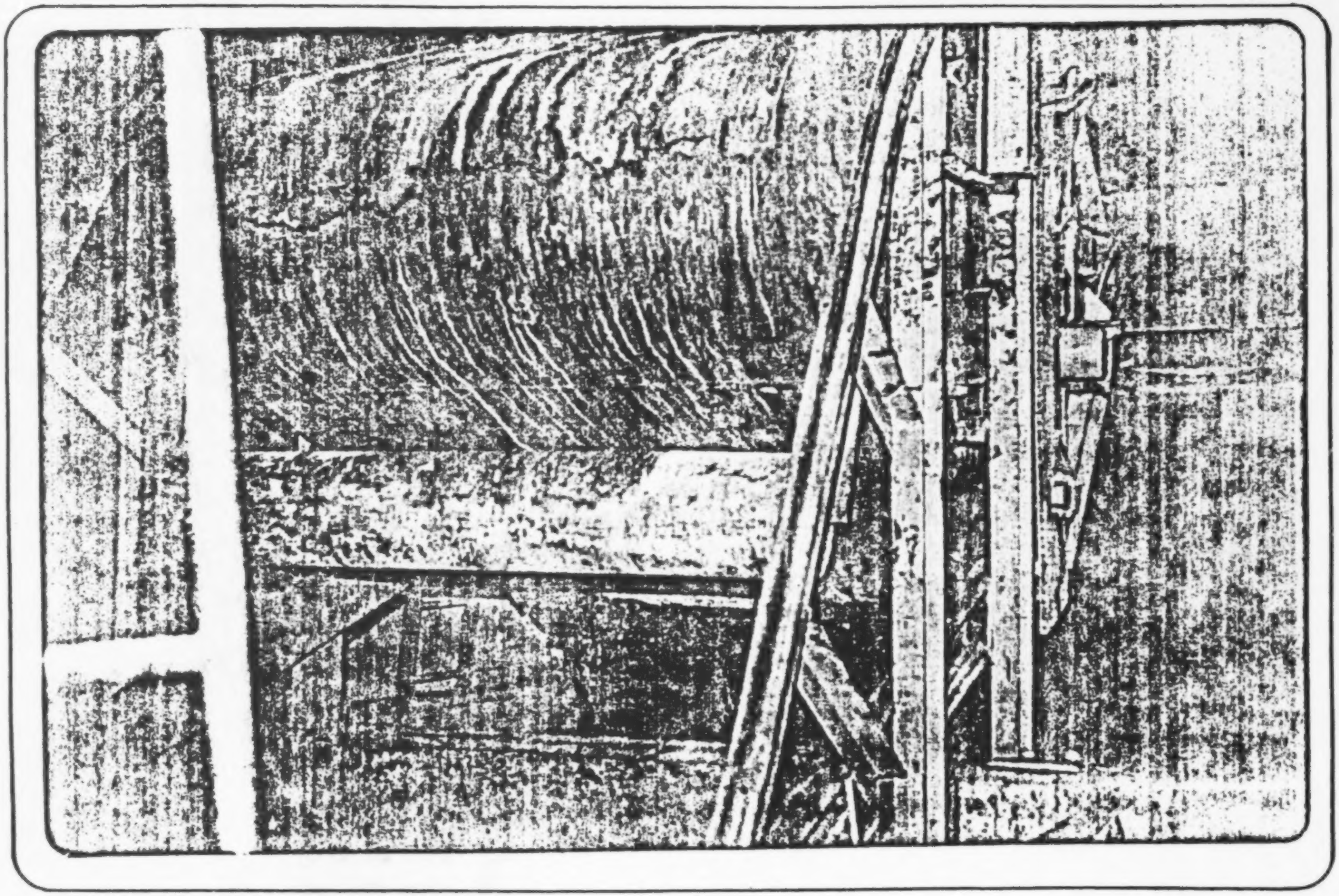

FIGURE R-31. SKIP HOIST DUMPING INCINERATOR ASH (SLAG) AT COPENHAGEN: WEST

Figure R-32 is a diagram of the ash recovery plant. The ash leaves the building and goes through a series of vibrators, sieves, magnets and conveyors as shown in Figures R-33 through R-36. The processed ash less than 45 mm is stored on the ash mountain.

Ash recovery. Ash recovery at Copenhagen: West is very advanced. It was the subject of a 42 page report (English version available) co-authored by the Danish Geotechnical Institute (DGI) and the Water Quality Institute (WQI) entitled, "Cinders and Reuse". Sections of the report were written by Mr. T. Balstrup (DGI) and by Mr. Sven Dige Pedersen (WQI). The report is divided into two sections. The Geotechnical Qualities of Cinders and Environmental Aspects Surrounding Combustion Cinders. Key paragraphs have been repeated where it would benefit this report.

Back in the early 1970's, when Copenhagen: West was conceived, the only clear alternative was to place cinders in a landfill with plastic liners and a leachate collection system. Even by 1972 useable research results were not available. Both WQI and DGI performed their work between 1972 and 1975. While research was being conducted, the plant continued to place unprocessed ash in the Vestskoven landfill.

The research provided the following applications:

Application 1. Base and foundation for small and lightly traveled local roads
Application 2. Bicycle paths
Application 3. Parking lots
Application 4. Below floor building construction
Application 5. Foundations carrying light loads

The following numbers reflect the normal annual operation:

Quantities

	Tonnes
Waste burned	240,000 to 300,000
Raw ash or crude cinders	50,000 to 75,000
Usable gravel cinders	40,000 to 600,000
Reusable billets	4,000 to 6,000
Ferrous metals	* na na

	*Ferrous Distribution
Caps and capsuls	20.8 percent
Indentifiable tin cans	10.9 percent
Metal strips, spoons, and scissors	10.4 percent
Nail and screws	11.5 percent
Scrap metal - big pieces	17.7 percent
Scrap metal - small pieces	28.7 percent

Fly ash is not physically combined with bottom ash and was excluded from the research because supposedly its cement-like properties would interfere with the gravel-like applications. Fly ash at Copenhagen:West is separately collected and separately disposed.

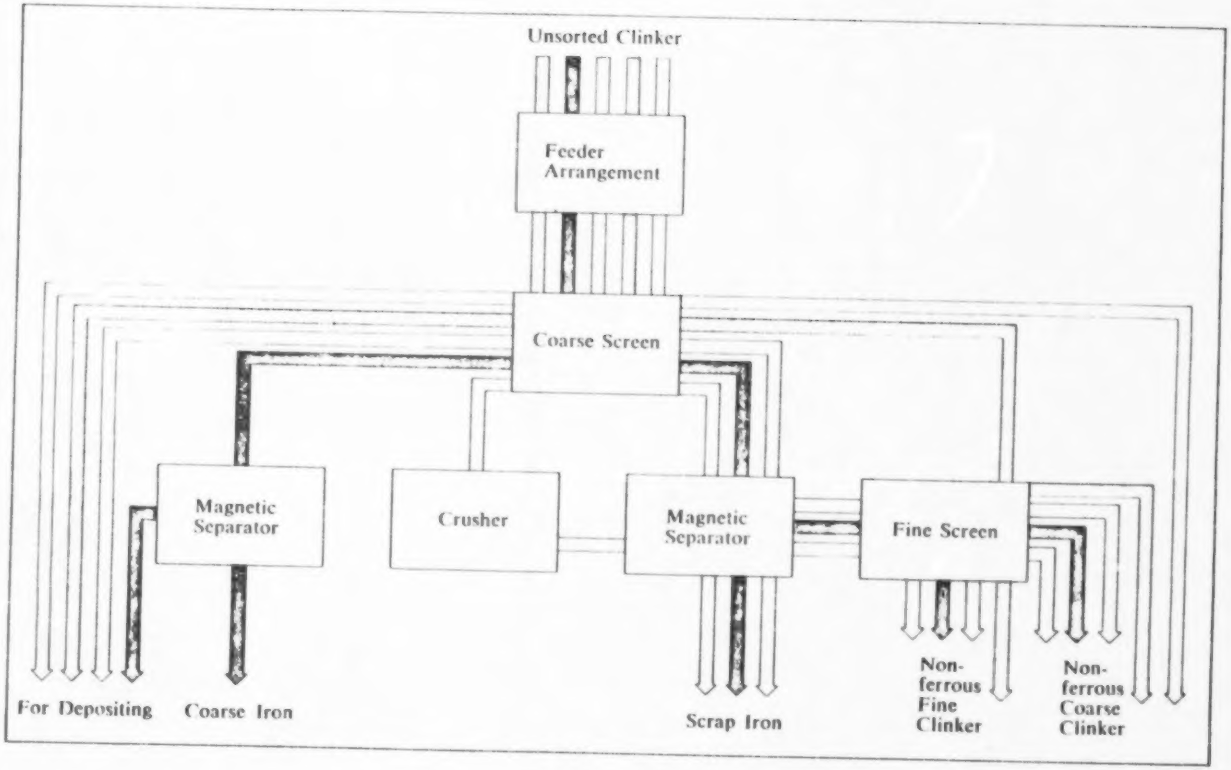
Unsorted Clinker
Feeder Arrangement
Coarse Screen
Magnetic Separator
Crusher
Magnetic Separator
Fine Screen
For Depositing
Coarse Iron
Scrap Iron
Non-ferrous Fine Clinker
Non-ferrous Coarse Clinker

FIGURE R-32. ASH HANDLING AND PROCESSING AT COPENHAGEN: WEST

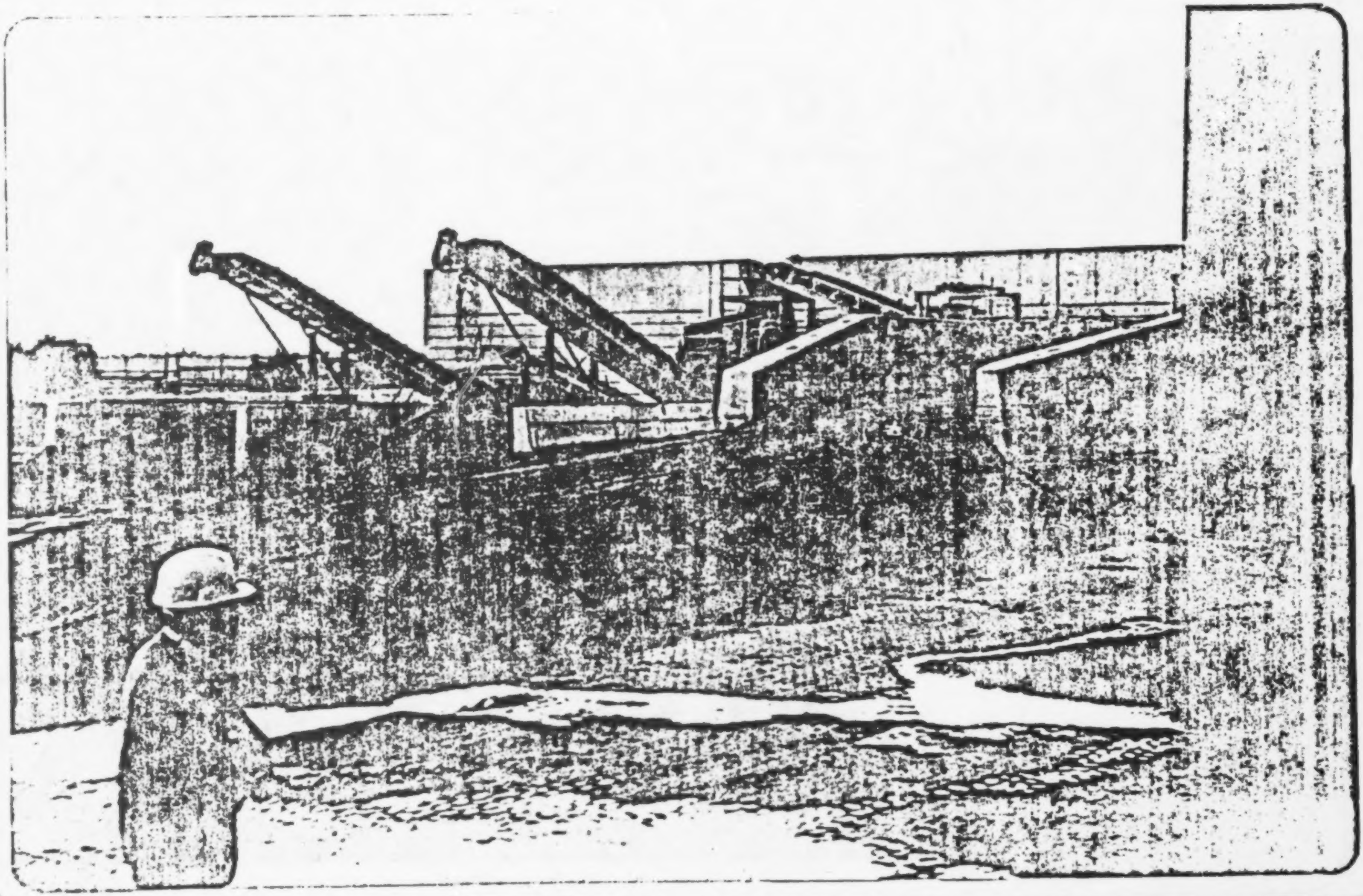

FIGURE R-33. ASH RECOVERY AT COPENHAGEN: WEST

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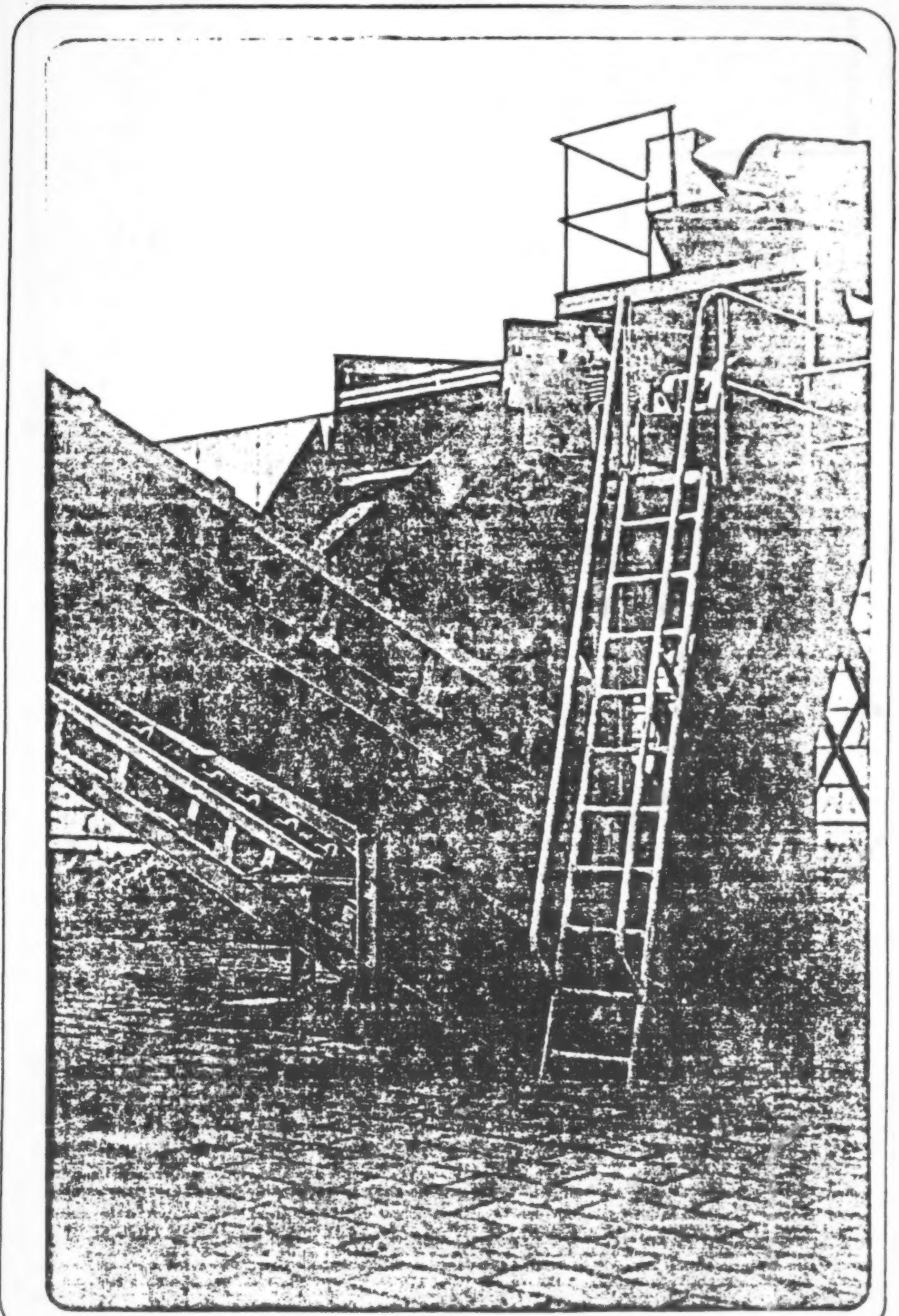

FIGURE R-34. VIBRATING MACHINERY FOR ASH PROCESSING AT COPENHAGEN: WEST

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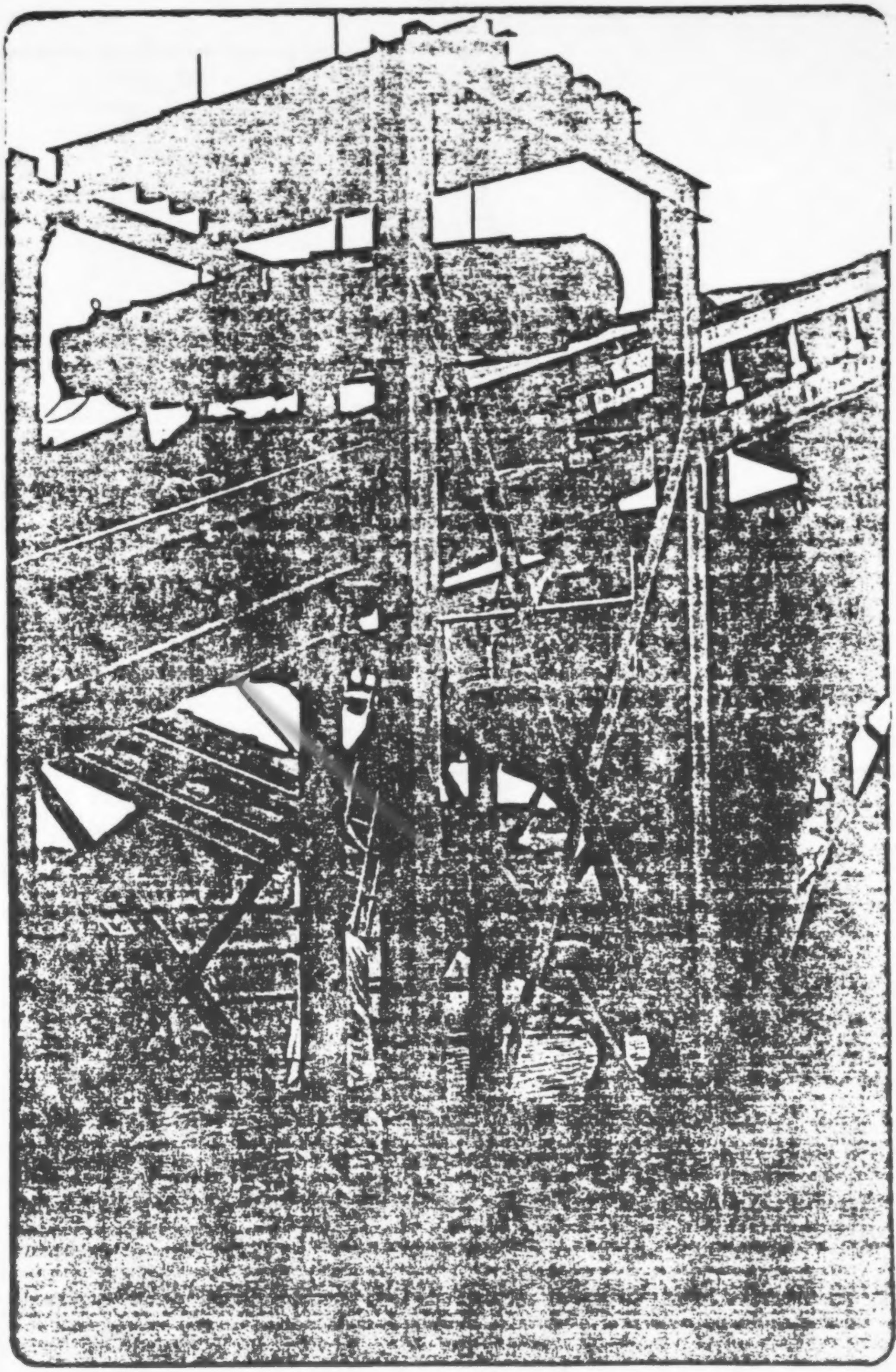

FIGURE R-35. FERROUS MAGNETIC BELT FOR ASH RECOVERY PROCESSING AT COPENHAGEN: WEST

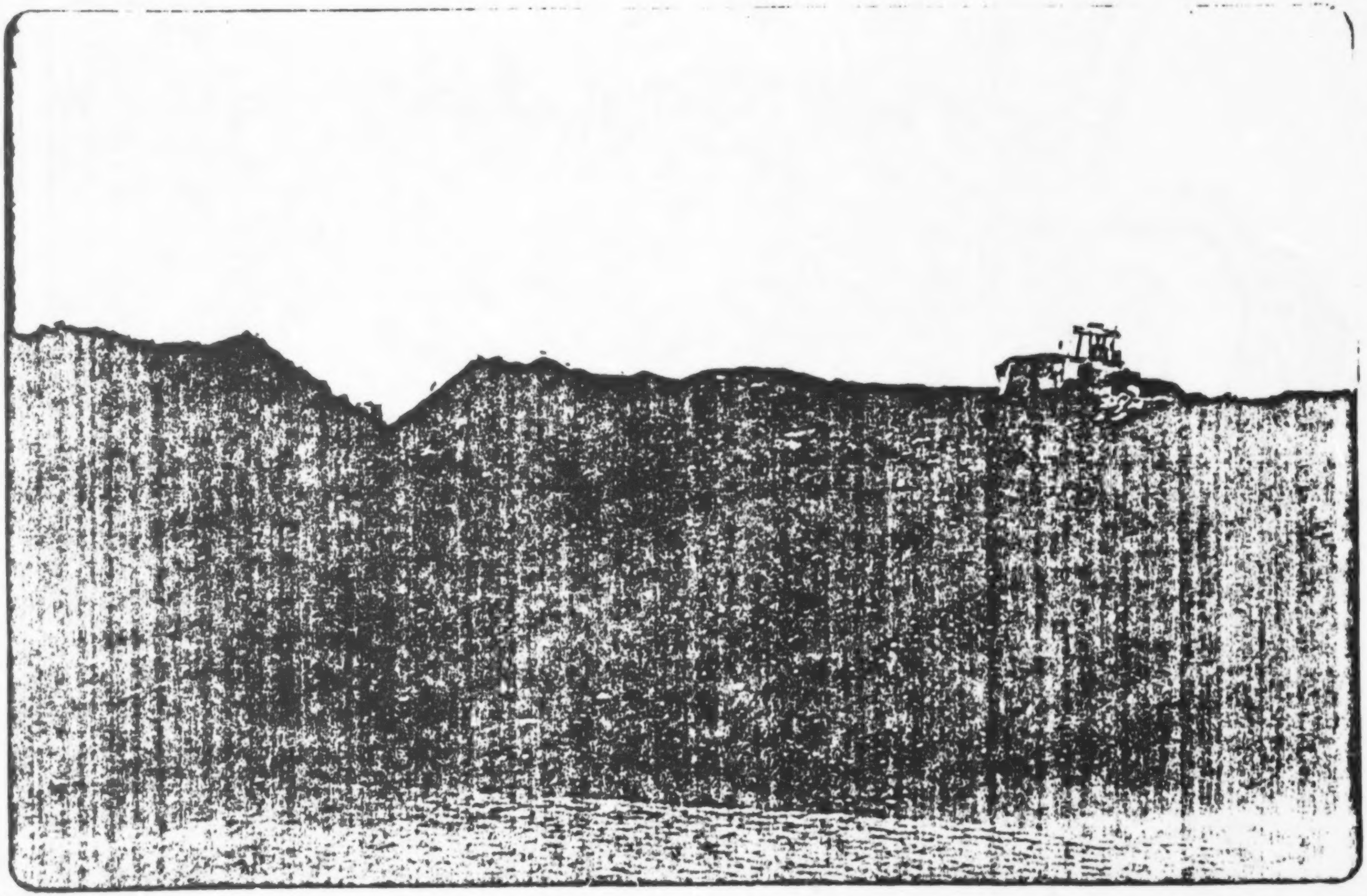

FIGURE R-36. MOUNTAIN OF PROCESSED ASH RESIDUE AWAITING USE FOR ROADBUILDING OR CINDER BLOCK MANUFACTURE AT COPENHAGEN: WEST

Road Test Procedures

" In order to establish a basis for initial evaluation and future control, it was decided by DGI to employ the same test procedures for the evaluation of sand and gravel materials. This was done with the full knowledge that they were dealing with a product of another grain structure, and without systematical experiences from full-scale plants."

" Laboratory tests included determination of grain density, ignition loss, grain distribution analyses (Figure R-37), density determinations by dry embedment and by Proctor tests, CBR test, permeability and capillary tests, and finally determination of strength and deformation characteristics by triaxial compression- and consolidation tests. Technical results are presented in the report. Furthermore, examinations have been made of crushing of grains of the cinders material by means of poundng processes, and the deformation of the built-in cinders due to repeated loads."

"At the conclusion of the combustion process the cinders are cooled down by watering. They subsequently have a moisture content near 20 percent which corresponds to the maximum quantity for building. Tests were carried out in a very rainy and cold period which did not change the moisture content of the cinders, as a satisfactory drainage through the cinders to the surrounding area took place."

"After sorting over a 45 mm screen which mainly retains tins and large pieces of iron, the cinders appear as a homogenous material. It is so esthetic that it does not resemble a waste product, and it can be used in populated areas without problems. The sorted out large material comprises only about 5 percent of the total cinders. In 1977, the process had matured so that now 20 percent of the total cinders is removed for ferrous recycling, reburning or direct landfilling. The cinders do not cause any special dust- or smell nuisances."

"The main results from the field test show that for the graded cinders a homogenous compacting is obtained which improves gradually with the number of roller passages. On account of the good stregth quality of the cinders, the compacting depth is limited. However, there is improvement when vibration equipment is used. By compacting to optimum density, a crushing of the grains of the cinders occurs. The drained layer of cinders will retain its optimum moisture content even during periods with plentiful precipitation."

"Laboratory tests furthermore demonstrate that a cemetation occurs, which in the course of three to four weeks will increase the strength and deformation qualities of the cinders by primary loads by 50 to 100 percent."

Parking Lot and Road Test Results

"A 15,000 m^2 (161,400 ft^2) parking lot was covered with 60 x 60 x 8 cm (12 x 24 x 3 inches) graded cinders with a 5 cm (2 inches) screen of gravel ahve been used. The cinders were laid out loosely in up to 40 cm (16 inches) thickness and compacted. After almost one year's use, only significant settlings (1 cm) have been registered."

"For a temporary road approach system with relatively heavy traffic in Herlev municipality, the graded cinders have partly been used as

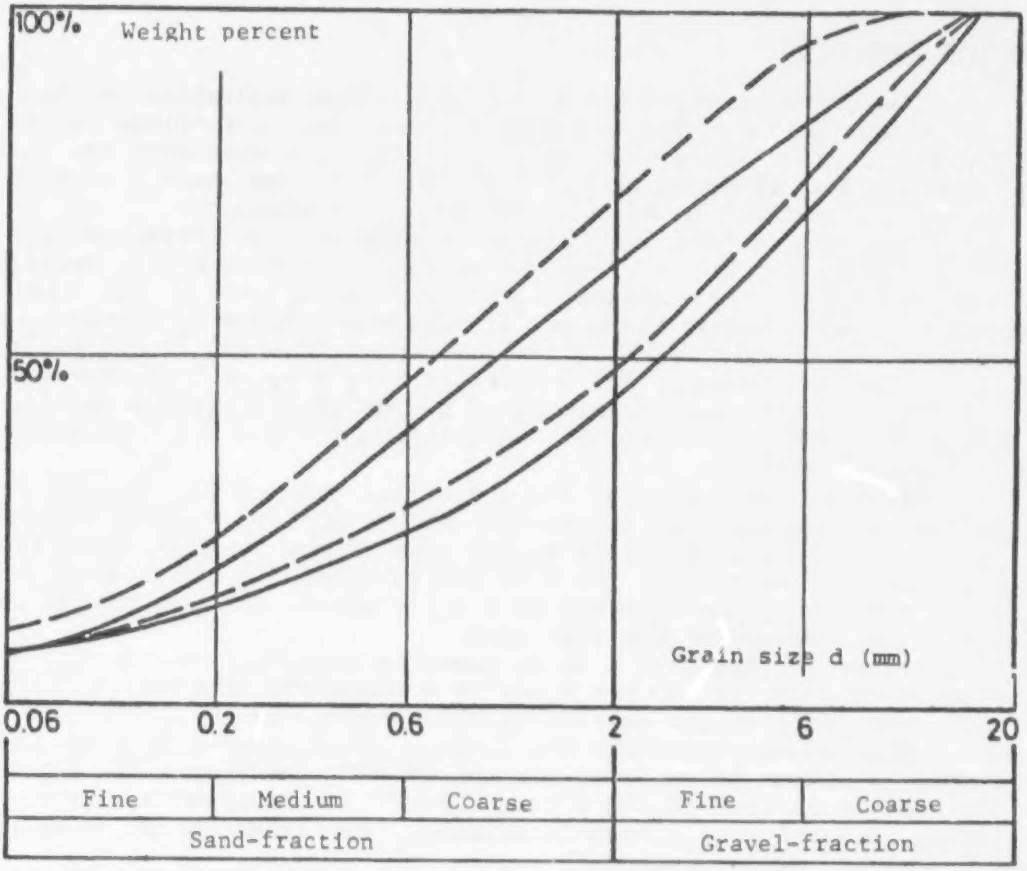

FIGURE R-37. The variation interval for the 16 mm fraction of graded cinders before (solid line) and after (dotted line) compacting by field tests.

foundation and base. The construction work shows that the compacted cinders without asphalt surface could carry the traffic without appreciable problems during the work period, even during a spell with plentiful precipitation, and that the compacted cinders by the successive replacement of the moist site deposits could stand with an almost vertical slope two to three meters tall. Settling and tracking tendencies will be followed for the finished construction."

"This road section of approximately 120 m (39 feet) is made from 7 cm (3 inches) gravel asphalt concrete, 13 cm (5 inches) stable gravel and 28 to 38 cm (11 to 15 inches) graded cinders. After completion of the road construction height surveys at 16 points of the road surface have been carried out in the period January 1976 to February 1977. The measurements indicate settlings of 0 - 5 mm. While the main part of the points with 28 to 38 mm indicate 5 - 10 mm frost heave in the period February - March 1976, the point which had been replaced with approximately 2 meters cinders had frost heave of 5 mm. The original soil base consists of medium solid marine clay."

"Finally, cinders have been used for foundations and base of local roads and parking lots for a school in Ballerup. The foundation and base of cinders was directly used as workroad during a period with precipitation and changing thaw and frost. Apart from local softening of the uppermost centimeter of cinders, no significant impediments for the work traffic were registered. The moisture content of the cinders under the softened zone correspond to the optimum level. Observations from these construction jobs so far seem to validate the use of cinders for road construction purposes."

Environmental Tests. Since the autumn of 1971, the Water Quality Institute (WQI) have carried out a series of tests for Copenhagen: West of the environmental apsects by depositing and use of combustion cinders. The following tests have been made:

- Accelerated washing out test on laboratory scale.
- Test of the washing out process form a non-covered cinders depot.
- Tests for characterization of graded cinders.
- Tests of the washing out process from a parking lot, where graded cinders are used as foundation material.

A most interesting and positive test result is caused by the pH of the cinders being around pH 9-11. The strong alkalinity in ash is due to the high concentration of carbonate. In this pH range, most of the heavy metals are insoluble. Thus leaching of the heavy metals into ground water is retarded. The next several paragraphs by Mr. Pedersen explain the environmental chemistry in greater detail.

Liquid Percolate (leachate), Fresh Water, Sea Water and Drinking Water Test and Results: Unprocessed Cinders at Special Sanitary Landfill

"The depositing of cinders was done in "depots", shaped like big hollows with the under-side two to three meters below ground. The dug out earth is put up like a circular wall, so that the hollows are four to five meters deep. On the inside the hollows are lined with a heavy, coherent plastic diaphragm in order to prevent penetration of the percolate to the groundwater. The percolate runs to a centrally located pump well, from which it can be picked up and analyzed."

"The object was to shed a light on the washing out process from an uncovered cinders depot, and to establish if there are traces of percolate in groundwater borings around the depositing site. Tests of secondary groundwater and percolate of cinders from the locality in Vestskoven where the cinders are deposited, were taken in the period from June 1973 to October 1975."

"No measurings or analyses of groundwater samples have evidenced any adverse influence from the percolate of cinders in this period."

"The concentration of macro ions (e.g. calcium, sodium, sulphate and chloride) in the percolate is of the same size as the concentrations in sea water."

"Among the examined trace elements, hereunder also heavy metals, only the concentrations of arsenic are bigger than the concentration in the groundwater samples in the test period from June 1973 to March 1974. However, it is substantially smaller than the drinking water criterion for arsenic."

"The concentration level for trace elements has not changed essentially in the period 1974/75. In Table R-4 analytical values of trace elements in the percolateare compared with the values for river water, sea water, as well as various drinking criterions."

"The main cause of the low concentrations of trace elements in the percolate is the high pH value (c.a.10) of the cinders which gives the percolate a pH value of approximately 9. At this pH level all examined trace elements are thermo-dynamically stable in a solid form. The trace elements are either immune (non-corrosive) or passive (coated with a dense skin of the corrosive product which prevents further corrosion) to attacks of water. The redox (reduction-oxidation) conditions in the depot (greatly reducing with hydrogen sulphide development) increases this tendency further, as possible dissolved trace elements from the topside of the depot will be tied up as very sparingly soluble sulphide deeper down in th depot. The presence of complexing ions (NH_4 +, Cl , HCO_3) will only to a lesser extent be able to increase the solubility."

"No higher solubility of trace elements than the one observed up till now can be expected, as long as the present pH- and redox conditions are maintained in the cinders. A noticeable change will first occur if the pH value of the cinders falls to pH 7 or lower. Such a change can only be caused by a neutralization of the alkaline parts of the cinders with acidic precipitation. The following calulation shows the length of time such a neutralization will require:"

Alkalinity of cinders: 0.975 equiv./kg
Acidity of rain water: 10^{-4} equiv./l (pH4)
Quantity of cinders in depot 1: 15,600 tons
Quantity of percolate per year: 452 m^3
"Neutralization time": $\frac{15,600 \times 0,975}{452 \times 10^{-4}}$ years = 336,500 years

"By the washing out from the depot some of the alkaline parts of the cinders are removed. This means that a neutralization of depot 1 would last less than the period indicated, but still a very long time (thousands

TABLE R-4. ANALYTICAL VAULES OF TRACE ELEMENTS IN THE PERCOLATE

Analysis Variable	Percolate 1973-74		Percolate 1974-75		Fresh-water Medium	Sea Water	Drinking Water Criterions			
	min.	max.	min.	max.			WHO	Sweden	USA	USA
Al	<1	1080	2.5	108	240	10		150		
As	4.5	16.5	10.6	20.5	0.4	3	50	200	50	100
Pb	2	<10	2	12	5	0.03	100	100	50	50
Cd	<0.1	<20	<1	<10	<80	0.1	10	50	10	10
Cr(tot)	10	<50	<5	80	0.2	0.05				50
Fe	7	370	<100	300	670	10	300	200	300	300
Cu	<1	80	<1	24	10	3	1000	50	1000	1000
Hg	<0.05	0.29	<0.05	0.25	0.08	0.03				2
Mn	29	300	30	50	12	3	100		50	50
Zn	10	150	25	60	10	10	5000	1000	5000	5000
B			<250	560	13	4600				(1000)
Se			2		<20	0.09	10	50		10
Ni			<50		10	5				-
Co			<50		0.9	0.3				-
Ag			40		0.1	0.3		50		-

Measured minimum and maximum concentrations of trace elements in percolate in the period June 1973 to March 1974, as well as March 1974 to October 1975, compared with the values for fresh water, sea water, as well as different drinking water criterions. All values are shown in ug/l.

last less than the period indicated, but still a very long time (thousands of years)."

Solid Processed Cinder and Soil Comparative Tests. By comparison with soil analyses, it can be seen (Table R-5) that the following elements in the cinders are present in a concentration which is greater than the upper limit of the range of distribution for concentrations in cultivated soil:

Cadmium
Chloride
Copper
Sodium
Lead
Sulphur (sulphate)
Zinc

Sodium and chloride mainly originated from wood and kitchen refuse (food scraps). A small part of the chloride may have been produced by the combustion of PVC which is present in the refuse in minute quantities. Sulphate is presumed to originate mainly from cardboard and paper waste. Zinc and cadmium are present in the ratio 460:1 which means that the main part of cadmium in the cinders has its origin as metal residues (pollution) in the zinc (normal ratio 100:1). The zinc is added from a great number of sources. Copper presumbaly comes mainly from electrical wire, and to a certain extent from copper-plated metal objects. Lead is presumed mainly to originate from food tins, paint, and painted articles which are dyed with lead pigment, as well as lead batteries.

The high pH value of the cinders, pH = 10.1, fixes the trace elements so that no significant quantities will be washed away from the cinders materials. In slightly acid surroundings, which may be found if cinders are spread and plowed down, the quantity of elements accessible for assimilation in plants will increase as the pH is lowered.

Test on Parking Lot in Ballerup. In the autumn of 1974, I/S Vestforbranding received permission to layout a 40 cm (16 inches) deep cinders as foundation of the parking area near Ballerup's town hall.

The Danish Environmental Protection Agency and Copenhagen's water supply plant wanted tests to be made of the drainage from the area. When the parking lot was built, a diaphragm was put under part of the cinders foundation, so that there was direct drainage from the lower side of the cinders material to a collection well. Furthermore, the whole area is drained, so that it is possible to collect drain water which has passed through the layer of gravel under the cinders.

Table R-6 shows the results cf tests of percolate, drain water, and water running off the surface of the parking area. The percolate from the cinders layer (sorted cinders) has the character of diluted percolate from the depot in Vestskoven, as it has been diluted four to eight times. The concentration of the trace elements lead, cadium, copper, and zinc is of the same magnitude as in the percolate from the Vestskoven depot, while the concentration of chromium is smaller.

During the passage through approximately 1 m (1 yd) concrete, gravel and the drain pipes, the percolate is oxidized, the ion strength is reduced,and the main part of the nitrogen is absorbed by the gravel.

TABLE R-5. ELEMENT COMPOSITION OF SOIL AND CINDERS (ALL ANALYSES MADE ON DRY MATERIAL)

Analyis Variable	Unit	Soil Variation Width /12/	Soil Average /12/	Cinders Average
Nitrogen	g/kg	0.2 - 2.5	1.0	0.66
Phosphorus	g/kg		0.65	2.71
Carbon	g/kg		20	12++)
Chloride	g/kg		0.1	81.5
Sulphate	g/kg	0.09 -2.7+)	2.1+)	10
Calcium	g/kg	7 - 500	13.7	32.2
Sodium	g/kg	0.75 -7.5	6.3	7.6
Magnesium	g/kg	0.6 - 6	5	2.6
Potassium	g/kg	0.4 - 30	14	3.2
Aluminum	g/kg	10 - 400	71	21
Arsenic	mg/kg	0.1 - 40	6	8.8
Lead	g/kg	0.002 - 0.2	0.01	1.56
Boron	mg/kg	2 - 100	10	<0.25
Cadmium	mg/kg	0.01 - 0.7	0.06	5.0
Chromium	mg/kg	5 - 3000	100	45
Iron	g/kg	7 - 550	38	28
Copper	g/kg	0.002 - 0.1	0.02	2.8
Cobalt	mg/kg	1 - 40	8	8.7
Mercury	mg/kg	0.01 - 0.3	0.03	0.13
Maganese	g/kg	0.1 - 4	0.85	0.88
Nickel	mg/kg	10 - 1000	40	73
Silver	mg/kg	(0.01 - 5)	(0.1)	4.6
Zinc	g/kg	0.01 - 0.3	0.05	2.3

+) : Converted from sulphur.

++) : Converted from carbonate.

TABLE R-6. COMPARISON OF ANALYSES OF PERCOLATE FROM DEPOT 1 IN VESTSKOVEN AND PERCOLATE, DRAIN WATER, AND SURFACE RUN-OFF FROM PARKING LOT IN BALLERUP

Analysis Variable	Unit	Percolate Vestskoven	Percolate Ballerup		Drain Water In Ballerup				Surface Run-Off Ballerup July
			April	October	April	July	July	Sept.	
pH		9.8		8.6	7.8	6.6-7.1	6.5	8.2	7.2
Conductive Power	mmho	21.4	6.20	3.27	2.10	3.03	3.23	1.91	1.19
Chloride	g/1	8.40	2.20	1.01	0.85	0.91	0.98	0.49	0.27
Dry Matter	g/1	19.2	4.81		1.75				
Ignition Loss	g/1		0.35		0.01				
Chemical Oxygen Comb.	mg O_2/1	36		26		10.4	12.4	3.9	10.4
Total Nitrogen	mg N/1	23.6		21.0		2.7	4.7	2.0	1.9
NH_3 Nitrogen	mg N/1	23.5	15.0	18.6	0.85			1.9	
Total Phosphorus	mg P/1	0.17		0.20		0.012	0.12	0.017	0.032
Sulphide	mg s^{--}1	11 - 102	3.12		0.04				
Lead	ug/1	12	<10	14	<10	<5	<5	10	79
Cadmium	ug/1	<5		<5		<5	<5	<5	<5
Chromium	ug/1	40		<5		<5	<5	<5	<5
Copper	ug/1	24		30	<10	8	6	11	17
Zinc	ug/1	25	<10	20		67	50	20	120

The concentration in the drain water of the trace elements lead, cadmium, chromium, and copper is less than or equal to that in the percolate before passage through the gravel layer, while the concentration of zinc is somewhat greater.

Water running off the surface had a lower chloride content than the drain water. The concentrations of trace elements in water running off the surface is bigger for lead (8 to 16 times), copper (1.5 to 3 times), and zinc (2 to 6 times), while it is of the same low size for cadmium and chromium.

During a situation in September 1975 with 21 mm (8.3 inches) of precipitation, the quantity of precipitation was removed from the area in the following way:

Evaporation:	41 percent
Surface run-off:	36 percent
Drainage:	23 percent

It has been calculated that with the use of a drain water quantity of 23 percent per year per m^2, a quantity of chloride is washed away from the cinders which corresponds to the quantiy of chloride which is added per m^2 roadway/parking lot when there are five to nine applications of road salt during the winter season. The washed out quantity of chloride per year will decrease gradually as the present chloride in the cinders is washed away. During the winter in 1973/74 there were 35 applications in Copenhagen, and on some of these occasions, salt was distributed twice, corrseponding to about 50 applications.

Furthermore, similar calculations show that the yearly washed out quantities of the trace elements lead, cadmium, chromium, copper, and zinc with the drain water from the area is smaller than the quantities which are added to the area yearly through precipitation from the atmosphere.

The calculations show that a very long period of time will elapse (thousands of years) before the alkaline parts of the cinders have been neutralized by acid precipitation.

The washed out quantities of substance with the drain water from the newly built parking lot will expectedly decline gradually as the area is consolidated and the joints between the flagstones become compact. So that the part of the precipitation which runs off the surface will constitute an increasing share,while the part of the precipitation which is removed from the area through drainage will constitute a decreasing share.

By using a dense surface dressing, such as asphalt and concrete, the washed out quantities of substance from the cinders, other things being equal, will be quite insignificant, as the quantity of drain water which is a presupposition for a wash-out of the cinders will be extremely modest.

Cinders as Excellent Landfill Cover Material. An alternative possible application for the cinders is the concentrated use of them to cover dumping grounds. Here the alkaline percolate from the cinders will help to reduce acid conditions in part of the dumping ground, so that the total washing out of trace elements from the dumping ground is reduced. However, the washing out of trace elements from the cinders themselves will increase as the pH is reduced.

Furnace Wall

General Comments

Most of the plants that were visited utilized water-tube cooling of the furnace wall. This type of wall has been translated from coal-burning to refuse-burning practice over the period since about 1960. In some cases the furnace is only partially water-cooled with the rest of the wall formed of conventional refractory. In all cases where wall tubes are used these tubes are a part of the boiler flow system. They are pressurized to boiler pressure and they supply a mixture of heated water and saturated steam to the boiler steam drum. Thus from a flow standpoint they are considered an integral part of the boiler system.

However, from the standpoint of combustion, the wall tubes are an essential part of the heat recovery from the flame that helps to cool the gases to a temperature level that is safe for them to pass on the super-heater and boiler convection banks. Thus the water-tube walls of the overall boiler system are treated here as a separate component of the combustion system while recognizing that they also constitute an important element of the overall boiler.

Furnace Requirements

The complex variety of furnaces now in use has evolved because of the interaction of several different requirements:

- Temperature: High pressure for steam power generation versus low-pressure steam or hot water for heating only. Low-pressure boilers are much cheaper to build, operate, and maintain.
- Size: Small furnaces need not be water-cooled if waste burning rates are moderate because the high surface-to-volume ratio of the small chamber facilitates cooling. Large furnaces are more likely to need water cooling because the wall surface is relatively small in proportion to the volume; hence, normal heat loss through refractory walls becomes insufficient to keep the refractory cool enough to survive.
- Refuse Heating Valve: The remarkable increase in heat value of European municipal refuse since World War II, which has markedly changed furnace wall design requirements.
- Fly Ash: The highly variable but active chemical nature of the fine ash produced, which can foul and corrode water-tube walls and boiler surfaces.

The heat value of waste underwent a steady rise as shown in Figure S-1 because:

- Residential heating was converted from coal to oil which produced no ash residue.
- Paper and plastic packaging of consumer products became widespread.

Thus, in 1965, Tanner* stated:

> "For, as the calorific value rises, the uncooled combustion chamber leads to chamber temperatures that can no longer be

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* Tanner, Richard, "The Development of the Von Roll Refuse Incineration System", Sanderdruck aus Schweizerischen Bauzeitung, 83 Jahrgang, Heft 16. (1965)

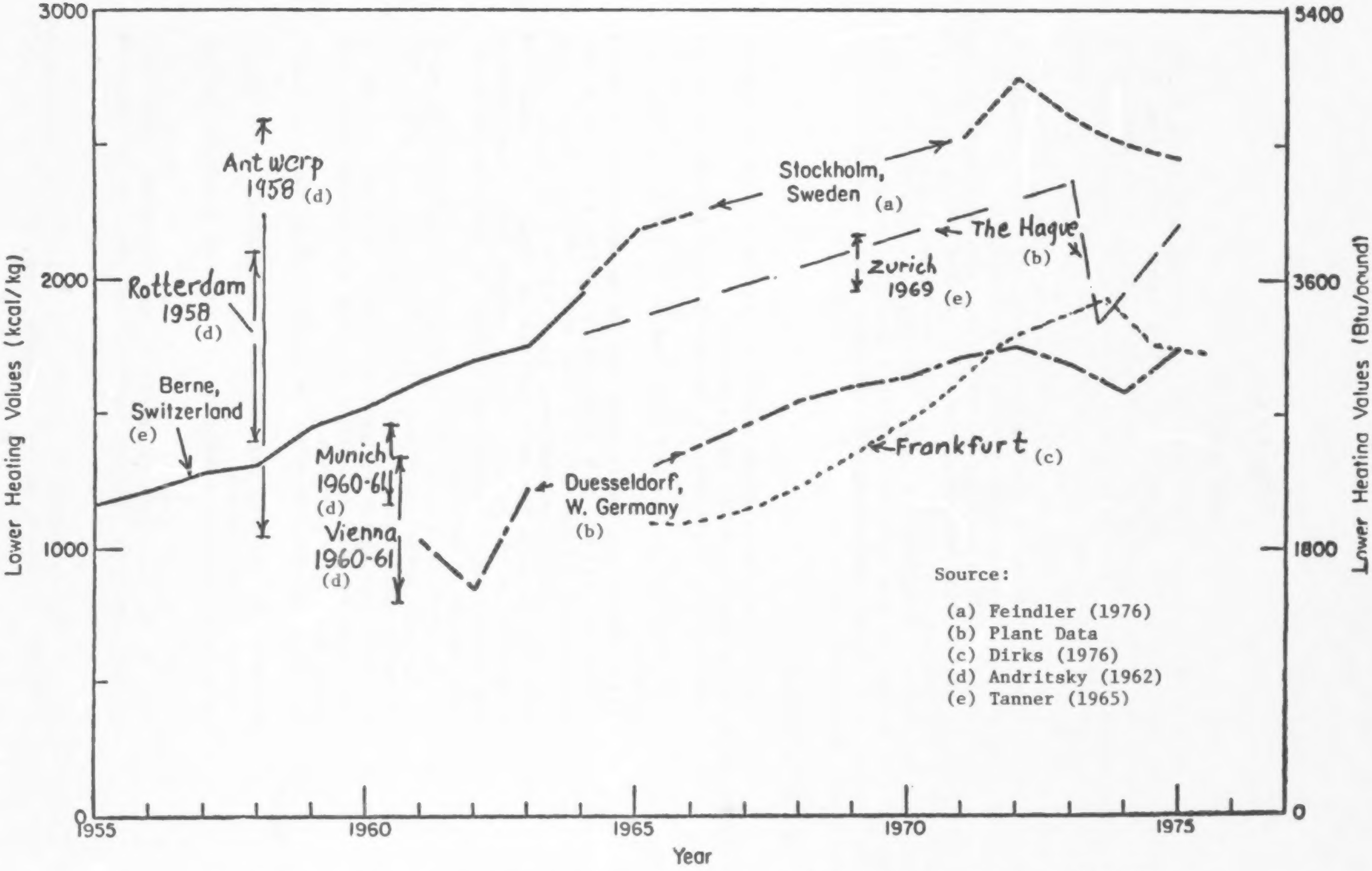

FIGURE S-1. ANNUAL AVERAGE LOWER HEATING VALUES FOR BERNE, STOCKHOLM, FRANKFURT, THE HAGUE AND DUESSELDORF AND RANGE OF VALUES FOR OTHER CITIES (See References at end of this chapter)

> controlled by air injection and fume feedback (flue-gas recirculation) alone. Thus, the adoption of radiation heating surfaces is becoming essential for refuse firing systems as it has long been usual in firing systems involving higher grade fuels."

In this latter phrase, Tanner was referring to the fact that coal- and oil-fired furnaces, once refractory walled, had by the late 1940's, been largely changed to water-tube wall construction.

A significant goal of heat recovery in these waste-to-energy plants is to cool the exhaust gases to a temperature level of (177 to 260 C) 350 to 500 F where reasonably sized, high efficiency electrostatic precipitators will be practical. However, up until the early 1960's, there was considerable reluctance to involve the waste heat boiler surfaces too closely with the furnace. In 1969, Hotti and Tanner[*] stated that a common earlier attitude was: "The combustion chamber must not be cooled. Designers thought that cooling would not permit reaching an adequately high combustion temperature". However, as the heat value rose, for example, in Berne, the average heat content rose from 1,160 Kcal/Kg (1,090 Btu/lb) in 1955 to 1,950 Kcal/Kg (3,510 Btu/lb) in 1964, rising furnace temperatures probably caused increasing troubles with refractory maintenance. Accordingly, Hotti and Tanner observed in 1969: "The trend of boiler development steered mainly toward adjustable radiation heating surfaces in the combustion chamber..." These same authors, Hotti and Tanner, then pointed out that at their next plant at Ludwigshafen in 1967, "...the radiation surfaces surrounding the combustion chamber can be studded and covered with rammed material or, alternatively, stripped bare, as required". An earlier plant at Helsinki in 1961 had also used water-tube-walls. Thus, with this company, the transfer of water-tube-wall technology from well-developed coal-burning practices to waste-to-energy plants occurred in the mid-1960's.

Meanwhile, the first large water-tube-wall boiler, 264 tons/day, had been installed at Essen-Karnap in 1960 as part of an existing coal-fired power plant described by Moegling[*]. Pulverized coal was fired above the refuse fuel bed.

During the same period, the Martin grate, originally applied to the burning of brown coal, was adapted at Munich to water-tube-walled furnaces for the large-scale burning of municipal refuse for power generation. Bachl and Mykranz[*] described the first Munich unit in an extensive article published in Energie, in August, 1965. Pulverized coal was fired in a separate furnace. In a second unit, the coal was fired directly above the refuse.

Another system was developed by the municipal utility at Duesseldorf during 1961-1965.

Air-Cooled Furnace Wall at Werdenberg

Figure S-2 shows a cross section of the single boiler in the small Werdenberg-Leichtenstein plant at Buchs, Switzerland. Although this is a very small boiler (12 tonne/hr (26,460 lb/hr) rated steam capacity with a peak capacity of 16 tonne/hr (35,275 lb/hr)), in many ways, it embodies the current culmination of evolution of the vertical pass, water-tube wall type of boiler discussed earlier. Boiler pressure is 40 atm (590 psia) (4,052 kPa). It began operation in April, 1974. Undoubtedly, a significant factor

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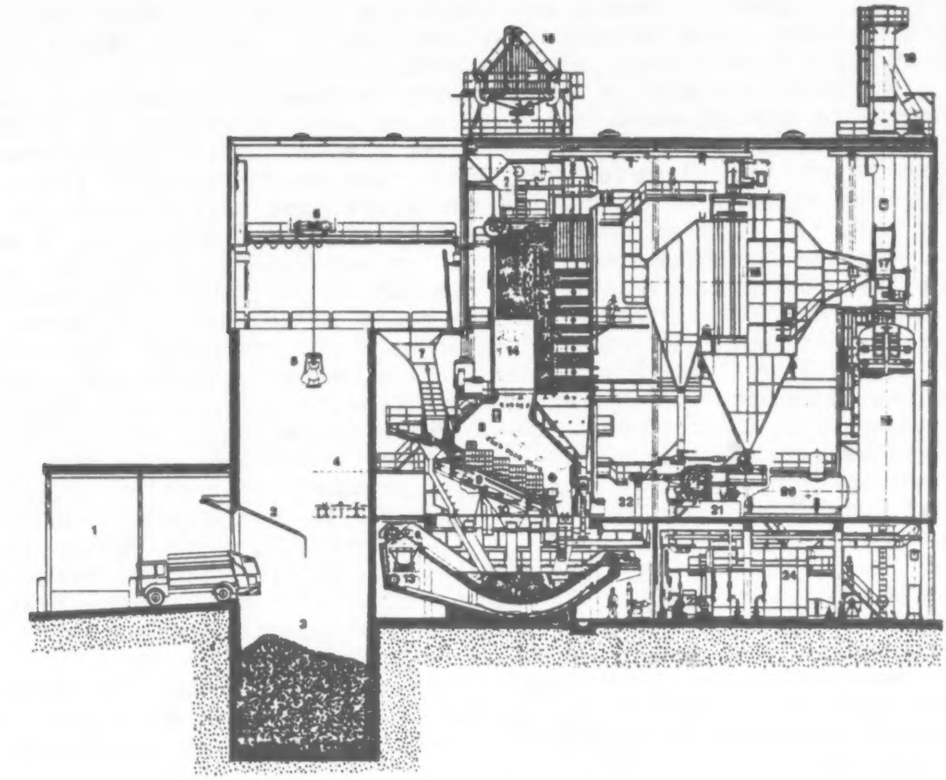
[*] Hotti, G. and Tanner, R., "How European Engineers Design Incinerators", American City, June, 1969.

[*] Moegling, E., "Praxis der Zentralen Mullverbrennung am Biespiel Essenkarnap", Brennst. - Warme - Kraft, 17, August 1965, 383-391.

[*] Bachl, H., and Mykranz, F., "Experiences With Refuse - Firing In A High - Pressure Steam Power Plant", Energie, 17 P. 317-26, August 1965.



1 Delivery Area
2 Bunker Door
3 Refuse Bunker
4 Crane Pulpit
5 Crane
6 Refuse Grab Bucket
7 Charging Hopper
8 Incinerator Furnace
9 Step Grate
10 Ash Hopper
11 Residue Chute
12 Residue Basin
13 Residue Conveyor Belt
14 Steam Boiler
15 Air Cooled Condenser
16 Electrostatic Precipitator
17 Exhaust Gas Fan
18 Steel Chimney
19 Hot Water Heater
20 Feed Water Tank
21 Turbogenerator
22 Collected Flyash Conveyor
23 Feedwater and Heating Water Pumps
24 Oil-Fired Stand-by Boiler

FIGURE S-2. PARTIALLY WATER-COOLED AND AIR-COOLED FURNACE AT WERDENBERG-LIECHTENSTEIN (Courtesy of Widmer & Ernest) in its design is the presence on the vendor's engineering staff of a number of experienced designers who had experience over the years working at Von Roll with the same Dr. Tanner referred to in the earlier paragraphs on boiler furnace evolution.

The sides of the furnace are composed of two different surfaces. Near to the grate and for about 1.5 m (4 ft) above, the grate wall is formed with about 85 air-cooled Kunstler (Zurich) cast iron blocks on each side which allows a small amount of cooling air to enter the furnace through narrow air gaps between adjacent blocks. The blocks are about 250 mm (10 in) tall and 20 mm (8.5 in) wide. Above the cast iron blocks, the furnace wall is formed by Plibrico Super AB plastic refractory 150 mm (6 in) thick backed up by 250 mm (10 in) high-temperature calcium silicate insulation. Figure S-2a is a diagram of the action of the Kunstler wall blocks.

Thus, the lower quarter of the main furnace sidewalls are cooled only by forced air flowing behind and through the wall blocks, but the front and rear wall of that chamber are cooled by water-wall tubes similar to the arrangement in the large, vertical open pass above the furnace. In the "rear wall", which actually is a rear "arch" which slopes a little more steeply than the sloping grate, there are 40 tubes closely spaced over the width of the furnace. The Widmer & Ernst engineer stated that the temperature in the furnace is 950 C (1,742 F).

This sloping rear roof is studded with 8 mm (0.3 in) diameter studs, 22 mm (0.9 in) long. There are about 1,000 studs per square meter. These tubes and studs are then coated with a 25 mm (1 in) thick coating of Plibrico Super AB plastic refractory. In the newer plants, 40 mm thick Plibrico coating is used. This thick coating reduces the heat absorption by the covered tubes but serves as a protection against corrosion. It has been very successful here and elsewhere. Apparently the decision to increase the refractory coating thickness from 25 mm (1 in) as used here up to 40 mm (1.6 in) in newer plants was made in order to increase the life of the coating, as this coating is subject to deterioration from cracking as it heats and cools. In addition, the coating is mechanically eroded and spalled by the action of heavy deposits of fused ash which adhere to the coating then break off or are broken off during periodic cleaning. As portions of the coating are broken away, patching is required to maintain protection of the tubes. Apparently a thicker coating reduces the frequency of patching required.

Welded studs and refractory coating are also utilized over the entire lower half of the vertical, water-tube walled boiler pass immediately above the furnace. This very common design of coating was applied after corrosion was experienced in 1970 in a similar furnace at Baden-Brugg, Switzerland, which required protection after only 2,000 to 3,000 hours of operation.

In the first pass, the water tubes are nearly tangent. The tubes are carbon steel, 76.1 mm (3.0 in) in diameter, 4 mm (0.16 in) thick, spaced on 78 mm (3.1 in) centers. Although the tubes are nearly touching, they are not connected by welded fins to form a membrane wall. Apparently, European boiler designers have been reluctant to use the welded fin, membrane wall type of construction because of differential expansion problems that might cause fatigue cracks to form. However, it is now beginning to appear in some designs. In addition to providing the advantage

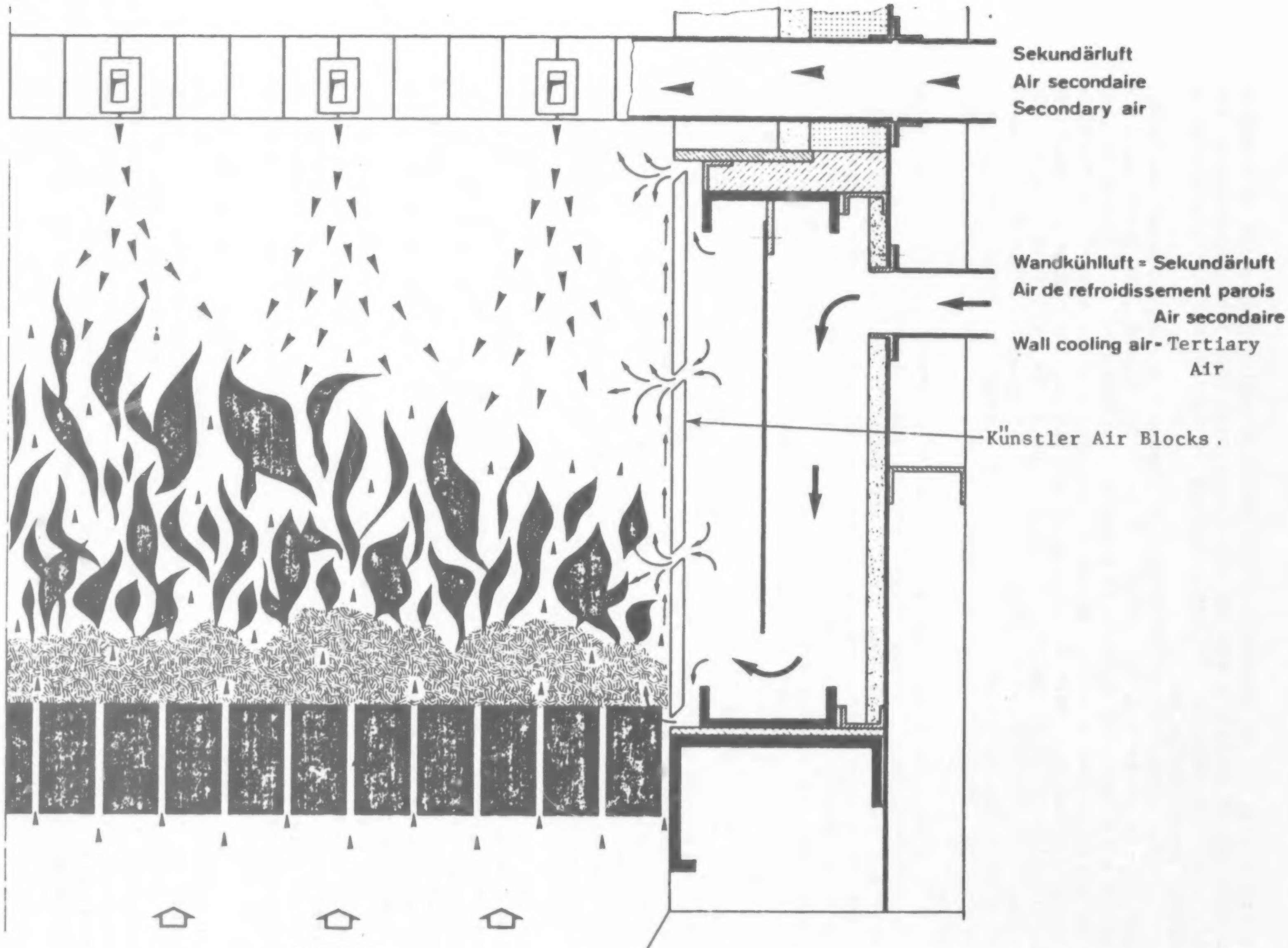

Sekundärluft
Air secondaire
Secondary air
Wandkühlluft = Sekundärluft
Air de refroidissement parois
Air secondaire
Wall cooling air- Tertiary
Air
Künstler Air Blocks.
Primärluft
Air primaire
Primary air

FIGURE S-2a. DIAGRAM OF APPLICATION OF KUNSTLER SIDEWALL BLOCKS (Courtesy of Widmer + Ernst) of air-tight wall construction, the welding of the tubes to form a "membrane" wall helps to keep all of the tubes in line and straight rather than allowing some tubes to bow inward or outward.

Second Boiler Pass. When the upward-flowing gases reach the top of the first pass, they then are turned horizontally into the entrance of a second water-tube walled vertical pass in which the gases are further cooled as they flow downward. These water tubes have no studs nor coating as, by this time, the gases are cooled so that corrosion and erosion are no threat to water tubes. This second pass for gas cooling is similar to the older and very successful Unit No. 3 at Zurich-Hagenholz described later.

Partially Water-Cooled Furnace at Baden-Brugg, Switzerland

Figure S-3 is a cross section of a portion of the 2-unit, two-boiler Baden-Brugg (1970) 200-tonne per day plant which is of interest because it preceded the one-boiler Werdenberg (1974) plant by 4 years and was designed by the same experienced designers.

A major difference from the later Werdenberg design is that, in this older design at Baden-Brugg, there is no open second pass to cool the gases before they reach the superheater.

The main furnace is largely refractory walled. Only the sloping rear wall of the furnace is water-cooled. As the combustion gases rise out of the partially cooled refractory walled furnace, they are accelerated into the first or radiation pass, a tall open, vertical, water-tube walled pass. The entering velocity to the pass is estimated to be about 5 m/sec (16.4 ft/sec). This is a relatively high velocity and, because of the eddies formed when the gases accelerate into this pass, this rather high velocity may have been partly responsible for early failure of nine wall tubes in the lower part of this first pass.

As a result of those failures, a 25 mm (1 in) silicon carbide covering was added over the lower 5 m (16 ft) of these walls. However, this increased the superheater outlet temperature 20 C (36 F). Hence, in 1974, in Boiler No. 1, the height of this covering was reduced to only 1 m (3.28 ft). The silicon carbide covering is not held in place by welded studs but by 20 mm diameter steel coils (see Figure S-4) which are anchored to the tubes before being buried by the plastic refractory covering. Since this coil-supported covering was applied, there have been no further failures of wall tubes. The wall covering now needs minor patching every year. Although this steel coil support for the refractory covering has apparently served well in this installation, the manufacturer has since used the more conventional welded steel studs at other plants to support the refractory covering on the sloping rear wall of the main furnace.

The manufacturer believes that the failure of nine wall tubes was caused primarily by reducing gases flowing against those tubes. The tube material is C14UN15462-64, a typical carbon steel. They are 57 mm (2.24 in) in diameter with a 2.9 mm (0.11 in) wall thickness, and are spaced 59 mm on centers.

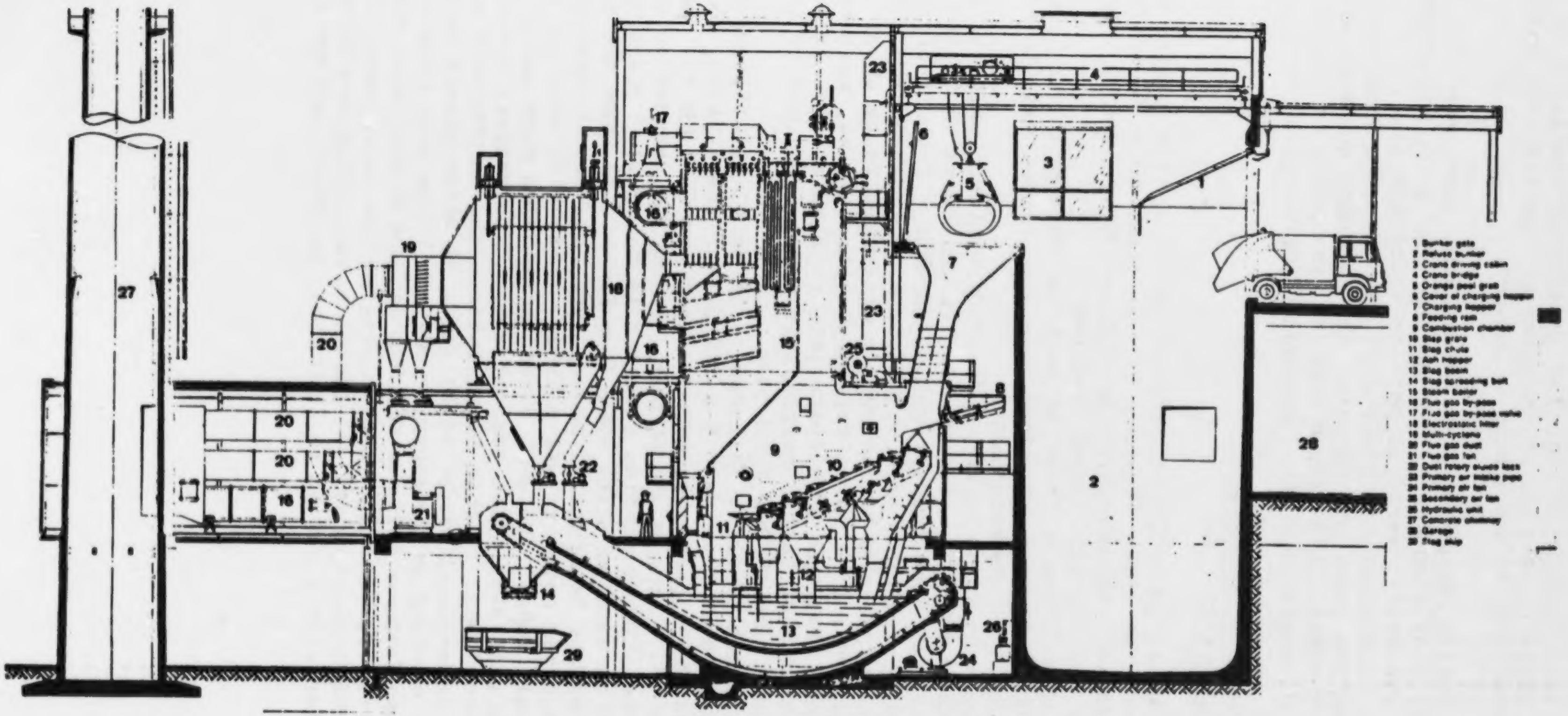

1 Bunker gate
2 Refuse bunker
3 Crane driving cabin
4 Crane bridge
5 Orange peel grab
6 Cover of charging hopper
7 Charging hopper
8 Feeding ram
9 Combustion chamber
10 Step grate
11 Slag chute
12 Ash hopper
13 Slag basin
14 Slag spreading belt
15 Steam boiler
16 Flue gas by-pass
17 Flue gas by-pass valve
18 Electrostatic filter
19 Multi-cyclone
20 Flue gas duct
21 Flue gas fan
22 Dust rotary sluice lock
23 Primary air intake pipe
24 Primary air fan
25 Secondary air fan
26 Hydraulic unit
27 Concrete chimney
28 Garage
29 Slag skip

FIGURE S-3. CROSS SECTION OF BADEN-BRUGG PLANT
(Courtesy Widmer + Ernst)

FIGURE S-4. HR. B. LOCHLIGER, ASSISTANT PLANT MANAGER, HOLDING STEEL REINFORCING COIL FOR TUBE-COVERING MOLDED REFRACTORY (Battelle Photo)

1965 and 1972 Designs of Furnace Wall in Duesseldorf

The five furnaces at Duesseldorf comprise an interesting example of the evolution of water-tube wall furnaces for mass burning over the past 12 years. When the first pilot grate was built at this plant in 1961, the use of water-tube walled furnaces for refuse was still in its infancy because the heat value of European refuse was very low. From 1961 to 1975 at the Duesseldorf plant, the average lower heat value of refuse increased 70 percent, 4,292 J/kg to 7,314 J/kg (1,025 kcal/kg to 1,747 kcal/kg (1,845 Btu/lb to 3,145 Btu/lb)) (see Figure S-5).

Thus, so long as wet, high-ash refuse made combustion difficult, designers were understandably reluctant to depart from the use of hot refractory-walled furnaces. However, as the heat value of refuse increased, furnace refractories were damaged by excessive furnace temperatures and the merits of water cooling the furnace and thus of adding it to the heat recovery loop became more and more attractive. However, the pilot plant at Duesseldorf, burning 8 tonnes per hour, utilized an old refractory-walled furnace, which had originally burned coal on a traveling grate at the Flingern Power Plant. This pilot unit, using the first roller grate, was operated intermittently for a total of 22,000 hours from 1961 to 1965 and provided the design basis for a small plant at Rosenheim, and for the first four full size units at Duesseldorf--the first of which was started in November, 1965.

For the reasons cited earlier, when the design transition was made in 1964-1965 from the old refractory-walled pilot furnace to the new, full-scale units, No. 1 through 4, there was an understandable reluctance to use a fully water-tube walled furnace. Although the lower heat value at Duesseldorf refuse had risen to 1,220 kcal/kg (5,108 KJ/kg) (2,196 Btu/lb) by 1963, that was still a relatively low level; hence, the need for some refractory in the main furnace to reflect heat to the raw refuse so as to facilitate rapid ignition and burning.

Accordingly, the water-tube walls of the furnace itself in Units No. 1 through 4, shown in Figure S-5, were protected by a 50 percent aluminum oxide refractory curtain 250 mm (10 in) thick and spaced by a dead air space 50 mm (2 in) wide in front of the vertical wall tubes. The tubes are 70 mm (2.75 in) in diameter with 5 mm (0.2 in) wall thickness. The distance between tubes is about 70 mm.

This type of unique sidewall construction was not used in Furnace No. 5, built in 1972, which will be described later.

The sloping roofs of the furnaces are also cooled by tubes covered by refractory.

First Open Boiler Pass, Units No. 1 Through 4. Burning is usually not complete as the gases flow upward out of the main furnace. This means that the ash particles carried in the burning gases are usually hot enough, over 982 C (1800 F), to be sticky. Accordingly, enough volume must be provided and that volume must be cooled for two reasons:

- Allow time for combustion to be completed, about 50 to 200 milliseconds
- Cool the gases so that deposits of ash particles will be dry and will be below the corrosive range.

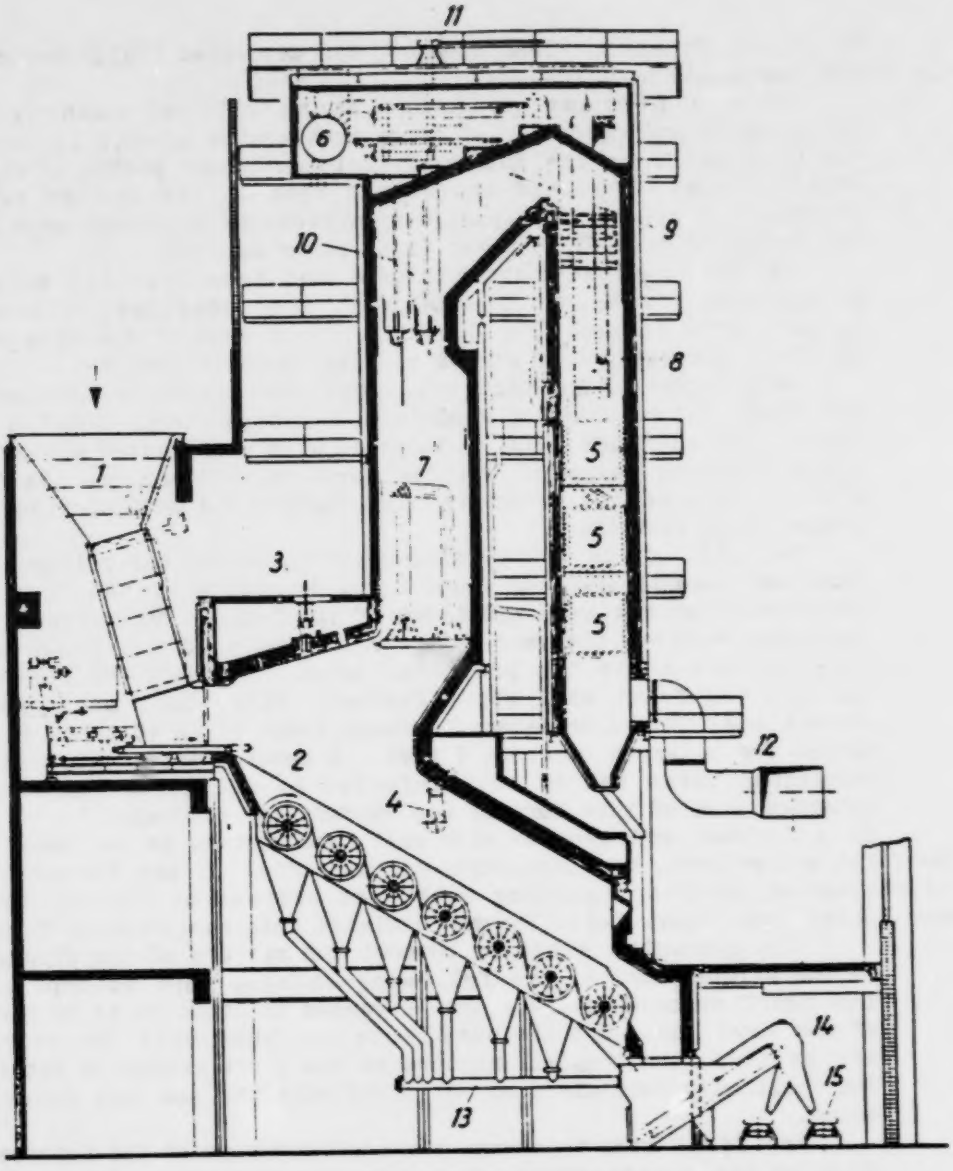


FIGURE S-5. CROSS SECTION OF ONE OF BOILERS NO. 1-4 (COURTESY OF STADTREINUNGS UND FUHRAMT DUESSELDORF)

1. Refuse hopper
2. Refuse feeder and roller grate "system Duesseldorf"
3. Ignition burner
4. Heavy oil burner (both sides)
5. Economizer
6. Steam drum
7. Radiant water-tube-wall boiler
8. Boiler convection section
9. First and second stage superheater
10. High-temperature superheater
11. Steam discharge
12. Exhaust gas duct to electrostatic precipitator
13. Ash siftings removal
14. Wet residue conveyor
15. Residue removal to processing plant

Mr. K. H. Thoemen, Plant Manager, has described (1972) the design of the first four boilers as follows*:

> "For different reasons, among others' economy, the construction and operation of large incinerator plants in Germany has been put into the hands of municipal power plants or similar institutions. This had the result that in the design of the incinerator plants, the same design elements have been used as in the design of coal-fired power plant steam boilers.
>
> In 1967, after tube failures had been reported at other incinerator plants, in Duesseldorf, the tubes just above the furnace were inspected and at the lower area of the side walls, the first indications of corrosion were found (Figure S-5).
>
> As a means of protection, additional secondary air nozzles were installed to build up a curtain of excess air in front of the tubes. Furthermore, the endangered area was studded and covered with a 1/2-inch layer of silicon carbide refractory. In other plants, this method of protection already has been applied, with similar good results.
>
> In 1968, a tube rupture occurred in one of our boilers. The cause was investigated and found to be corrosion by the flue gas. Subsequent extensive inspections of the boilers demonstrated that corrosion observed the year before had continued and reached the tube surface above the protected area. Not only the side walls but now the front wall was affected. Ultrasonic measurements showed that it was necessary to renew about 30 to 40 tubes in each boiler for a length of about 7 feet. A considerable number of the remaining tubes had to be reinforced by welding. Moreover, an extended area of tube surface was studded and concealed."

In a further endeavor to stop wall tube wastage in the lower part of the first boiler pass, more secondary air was added in the furnace roof and a refractory arch or "guiding wall" was evolved at the top of the furnace outlet (see Figure S-6). Thoemen explains this evolution as follows:

> "To guarantee a better burnout and mixture of the flue gases in the existing units, the following changes were accomplished. The overfire secondary air was increased to about 25 to 30 percent of the total air. But the experience is, that with the overfire air by itself, a complete mixture of the gases cannot be obtained. The relatively cold air does not blend with the gas but pushes it aside.
>
> The first step to change the configuration of the furnace was done by the construction of a fire guiding wall. This is an arch-like wall of firebrick, built in at the end of the furnace front-roof. This guiding-wall hinders the direct flow of the gases along the roof into the first flue. Furthermore, it is a contraction of the profile of the furnace throat by which part of the gas with high excess air from the end of the gases is forced into the front part of the furnace. Because the secondary air nozzles are located directly in front of the wall, a better vertical intermixture of air and gas is achieved. The arch-like configuration of the wall contracts the gas flow in the center of the first flue which results in a more uniform directed gas stream.

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* Thoemen, K. H., "Contribution to the Control of Corrosion Problems on Incinerators with Water-Wall Steam Generators", Proc. ASME 1972 National Incinerator Conf., New York, 310-318.

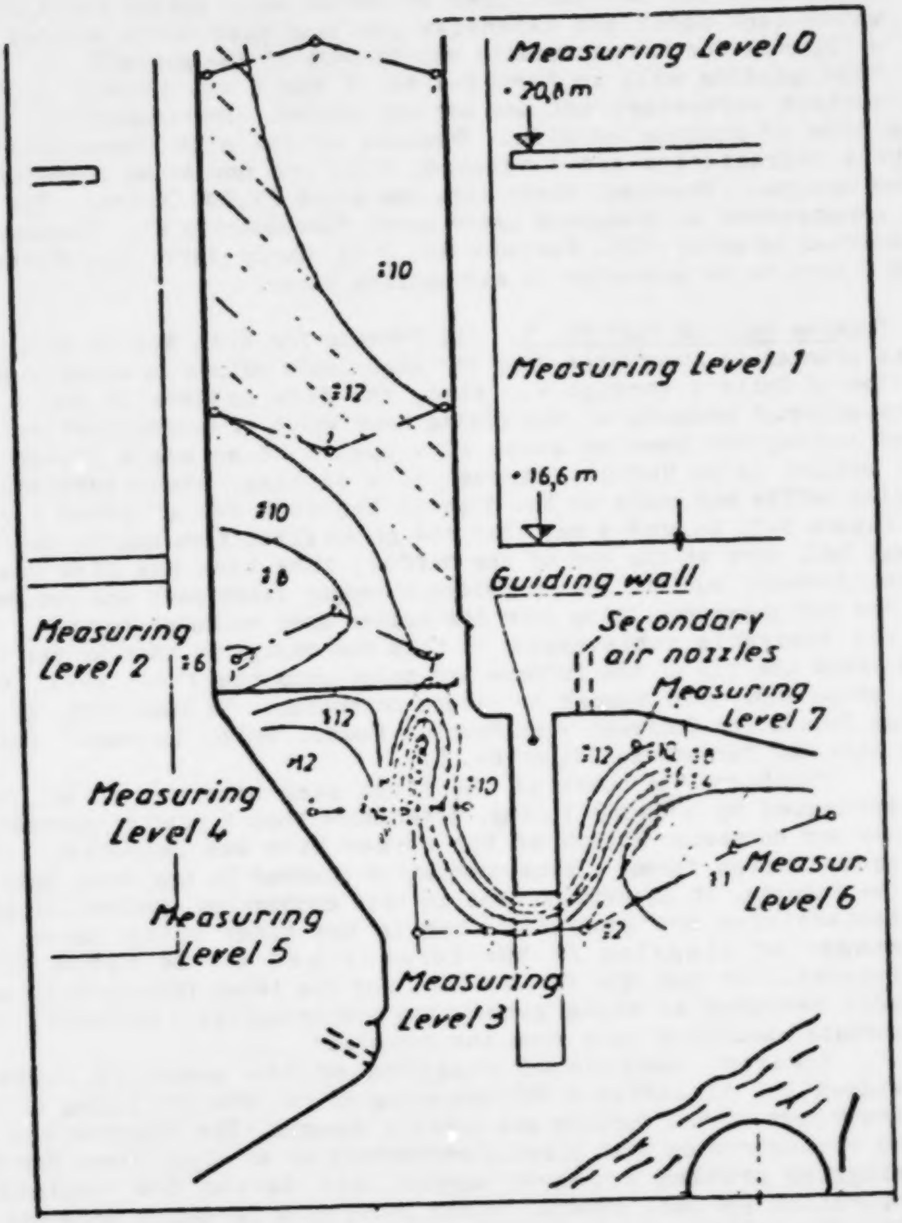
Measuring Level 0
•20,8 m
:10
:12
Measuring Level 1
•16,6 m
:10
:8
Guiding wall
Secondary air nozzles
Measuring Level 2
:6
Measuring Level 7
:12
12
:10
:12
:8
Measuring Level 4
Measur. Level 6
Measuring Level 5
:2
Measuring Level 3

FIGURE S-6. DIAGRAM OF LOCATION OF GUIDING WALL AT TOP OF FURNACE OUTLET SHOWING EFFECT ON OXYGEN DISTRIBUTION IN GASES

> The experience with this guiding-wall is very good. Since its erection in the years 1968 and 1969, tube corrosion in the first pass has not continued or spread out. Stream tests with a water-tank model and extensive gas analyses have proved the efficiency for the uniformity and burnout of the gases."

This guiding wall in Furnaces No. 1 and 2 was formed of high alumina content refractory and was not air cooled. In Furnaces No. 3 and 4, it was made of silicon carbide. Because of the high temperature to which these refractories are subjected, they are now being converted to air-cooled designs. Uncooled, their life was about 23,000 hours. The air cooling arrangement is discussed later under "Secondary Air". Furnace No. 4 was converted in early 1976, Furnace No. 3 in early 1977, and Furnaces No. 1 and 2 were to be converted to air cooling later.

Furnace Wall in Unit No. 5. The furnace for Unit No. 5, built in 1972, was altered in accordance with the experience gained in about 6 years of operation of Units 1 through 4. Also, the flow pattern in No. 5 was radically altered because of the rising heat value of Duesseldorf refuse. Instead of having the burning gases flow upward at an angle toward the furnace outlet as in Units 1 through 4, a sloping, steam-generating, water-cooled baffle was built in No. 5 above the fuel bed as shown (Point "A") in Figure S-7, in such a way that the gases first flow nearly parallel to the fuel bed; then at the end of the baffle, they turn and flow upward toward the furnace outlet. This provides a longer flame path and residence time for the hot gases resulting from the higher heat value of refuse.

One desirable achievement of this new design is that by the time the gases reach the top of the furnace and pass into the first pass, they are well mixed and cool enough to reduce corrosion. In late 1976, at the Engineering Foundation Conference at Hueston Woods, Ohio, Thoemen* stated regarding this new furnace in Boiler No. 5:

> "Although the tubes of the first pass have not at all been protected by ceramic lining, after more than 1 year of operation, not any corrosion attack of the former kind was detected... The construction forms a true combustion chamber in the front part of the furnace. It is evident that in this combustion chamber, higher temperatures are generated than in the elder units; hence, the danger of slagging in the furnace had to be taken into account...so that the furnace roof and the later fire-guiding wall were designed as steam generating water-walls, to carry off certain amounts of heat from the furnace."

However, because of slagging of the uncooled furnace sidewalls, "...after 6,000 operating hours, the SiC lining of the front part of the furnace was totally damaged. The furnace had to be reconstructed with plastic refractory on an Al_2O_3 base. Now the slagging problem appeared again, and during the following operation period, several times heavy slag formation occurred at the side walls, which made it necessary to shut the boiler down and remove the slag. In order to achieve a further undisturbed operation, the combustion was shifted to the end of the grate. Instead of air, recycled flue gas was injected under the first roll of the grate. Due to the oxygen reduction in the forward combustion chamber, the main combustion zone moved one roll

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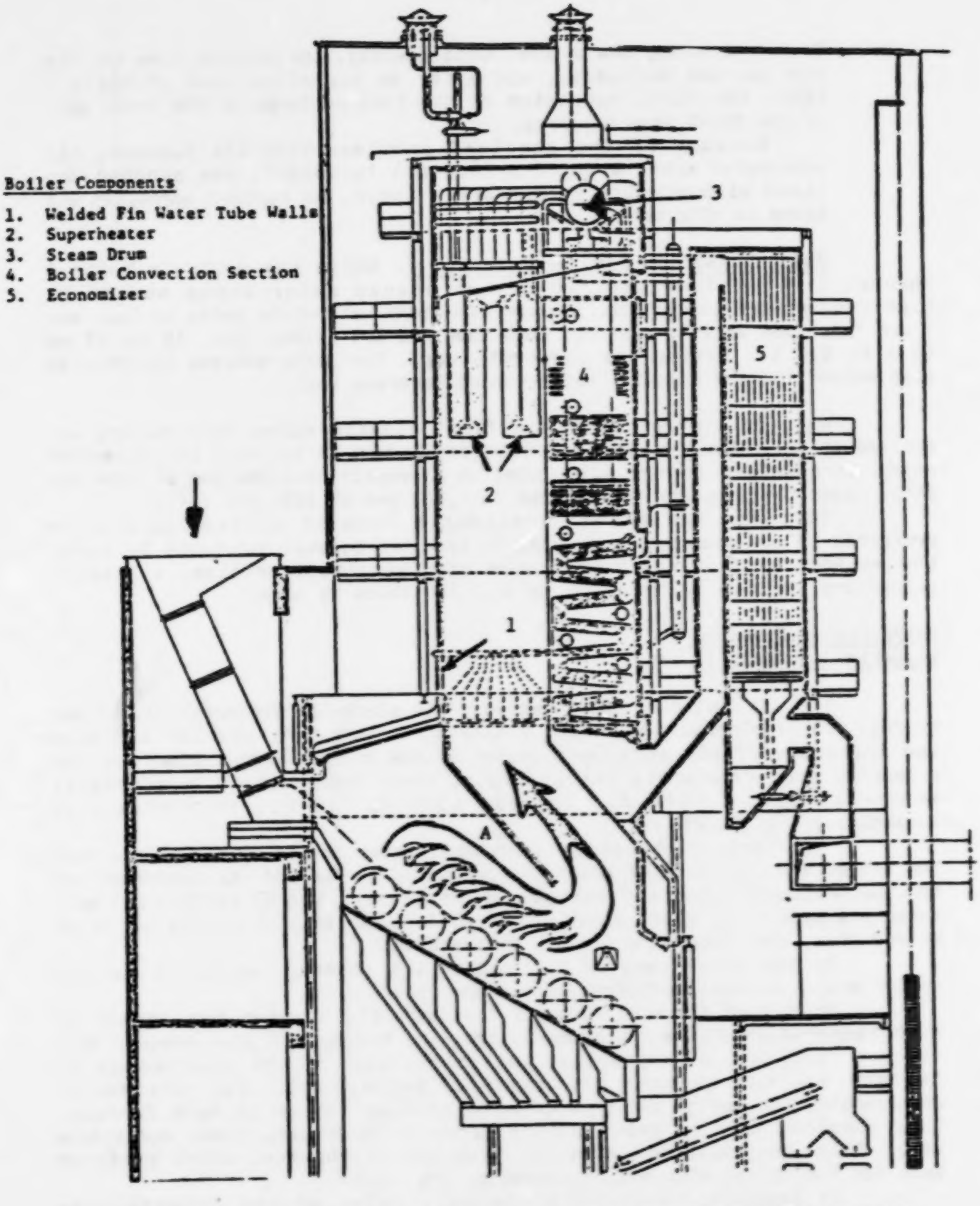
* Thoemen, K.H., "Contribution to the Control of Corrosion Problems on Incinerators with Water-Wall Steam Generators", Proc. ASME 1972 National Incinerator Conf., New York, 310-318.



Boiler Components

1. Welded Fin Water Tube Walls
2. Superheater
3. Steam Drum
4. Boiler Convection Section
5. Economizer

FIGURE S-7. CROSS SECTION OF BOILER NO. 5 WITH ROLLER GRATE "SYSTEM DUESSELDORF" (Courtesy Stadtwerke Duesseldorf Kraftwerke)

> downward along the grate. Consequently, the burnout time for the flue gas was shortened, and after an operation time of about 1 year, the first corrosion on the tube surfaces of the front wall of the first pass occurred.
>
> Because of the unsolved problems with the furnace, the endangered area, about 2 m (6.5 ft) in height, was studded and lined with plastic refractory. Later, no further corrosion was found in this zone."

Wall Construction in Unit No. 5. While the walls in Units 1 through 4 were either refractory or spaced water tubes backed by high-temperature insulation, the nonrefractory water-tube walls in Unit No. 5 are "membrane walls"; that is, each tube has two welded fins, 10 to 12 mm (0.4 to 0.5 in) facing the adjacent tubes. The joint between the fins is also welded forming a solid, water-cooled membrane wall.

Wall Protection. When the first plastic-refractory coating was applied to water-tube walls at Duesseldorf, the 10 mm (0.4 in) diameter studs were welded to the wall tubes at a density of 2,800 per m^2 (260 per ft^2). Later this density was reduced to 2,200 per m^2 (204 per ft^2).

To cover the studs, a moldable form of silicon carbide is preferred if an accumulation of slag is expected because SiC tends to repel the adherence of sticky slag. Where slag is little problem, a plastic refractory, such as Plibrico, 75 mm (2.9 in) thick is used.

Water-Cooled Furnaces at Wuppertal and Krefeld

The six units at the relatively new plants of Wuppertal (1976) and Krefeld (1976), Germany, both near Duesseldorf, are very similar and show the influence of the experience gained by VKW at Duesseldorf. They are not primarily power generating units; hence, steam temperature is moderate: Wuppertal (350 C, 662 F), Krefeld (376 C, 709 F), in contrast to Duesseldorf (500 C, 932 F).

Their furnaces are thoroughly water cooled in accordance with the design and operating experience accumulated by VKW and its customers at the Duesseldorf plant and various other plants. The 57 mm (2.3 in) wall tubes are made of ST 35.81 steel, 4 mm (0.157 in) thick; and by means of welded fins, they form a continuous membrane wall.

At the lower part of the combustion chamber, adjacent to the roller grate, precast carbofrax blocks are used.

To protect the wall tubes of the combustion chamber from attack by high-temperature flame impingement, they are studded and then covered with silicon carbide. At Wuppertal, initially, part of the coating is 50 percent SiC and another part uses 80 percent SiC. For purposes of observation, the amount and type of each coating varies in each furnace. They consider this an experiment to observe which meets their conditions best. Later they will settle on the type and arrangement which performs best for future use when any replacements are needed.

At Krefeld, to protect the wall tubes of the furnace from high-temperature flame impingement, they are studded and then covered with 90 percent silicon carbide. The welded steel studs are 10 mm (0.4 in) in diameter and 20 mm (0.8 in) long. The silicon carbide coating is approximately 50 mm (2 in) thick. The studs are applied at the rate of 2,100 per m^2 (195 per ft^2). The studs and coating are continued upward into the radiation chamber for a distance of about 3 m (10 ft) above the refuse feed opening.

At Wuppertal, as an extension of the protection afforded by the SiC, the same coating is carried upward along the walls of the radiation chamber for 2 or 3 m (6.5 to 9.8 ft).

During initial operation, water-washing of the boiler heating surfaces was used periodically for cleaning. However, this probably posed some threat through soaking of the refractory coating in the lower part of the radiation chamber and combustion chamber. Water-washing is no longer used. Instead, every 3,000 to 4,000 hours the surfaces are brushed clean manually. So far, there has been no slag buildup anywhere in the system; hence, only fine ash deposits need to be brushed off. This is unusual, since many other waste-burning furnaces require periodic cleaning of heavy deposits of fused ash and slag that adheres strongly to the sidewalls of the combustion chamber. We can only conclude that these relatively new furnaces are not being fired as intensely as are many others.

Because of the fact that the flue-gas scrubbing system is not yet operational at Wuppertal, only two of the four furnaces are operated at a time so as to limit the discharge of acid gases to the atmosphere. As has been observed at several of the 30 visited plant, waste generation rates leveled off in the mid 1960's and many plants were left with excess capacity. Thus, since the beginning of plant operation in January, 1976, and up to the time of our visit, May 20 and 26, 1977, or during an elapsed time of about 11,000 hours, each of the four boilers had operated only about 4,000 to 5,000 hours. While the intermittency of operation would not preclude excessively intense operation of each boiler during brief periods, the practical matter is that alternate means had obviously, already previously been employed for disposal of the 525,600 tonne/year, which is the theoretical full-time capacity of all four units potentially now available. Thus, there may as yet be no great need nor perhaps much pressure from any quarter to opereate the MVA units more intensively. (Actually, as designed, this plant was intended to operate only three boilers at a time, leaving the fourth unit for maintenance and standby).

From previous experience in the boiler industry, Mr. Temelli, Assistant Plant Manager, indicated that he is fully aware of the multiple problems of corrosion, erosion, and frequent maintenance requirements of combustion and thermal equipment when it is severely overloaded. He explained that because of the variable nature of refuse, if the nominal load per furnace is 15 tonnes per hour (16.5 tons/hour), peaks will be encountered of 18-19 tonnes per hour. To avoid the added maintenance resulting from such peaks, these units are now operated at an average rate of 13 tonnes per hour (14.3 tons/hour) or about 13 percent under rating. Since there is no immediate need to more fully load these units, they will probably continue to be operated conservatively.

So far, there has been no wall- or boilertube corrosion observed after nearly 6,000 hours of operation of each unit. They are designed to deliver steam at the rate of 46,000 kg/hr (101,200 lb/hr) (50.6 tons/hr) at a temperature of 350 C (662 F) and 27 bar (378 psia) (26.65 atm) or 2604 kPa.

An unusual feature of the Krefeld furnaces is that dried sewage sludge is fired in suspension in hot flue gases at a point near the lower end of the radiation chamber and within the section that is coated with silicon carbide. A substantial amount, 2.7 to 3.9 Nm^3/sec (5,715 to 8,356 scfm), of hot flue gases are extracted from the first pass and is sent to the sewage sludge hammermill. Because the sludge particles still carry moisture (10 percent) and because the moisture having been vaporized out of the sludge is still in the hammermill exit gas, when both the particles and the vapor enter the hot radiation chamber,they will absorb considerable heat before the particles become heated to their ignition temperature. For these reasons, there is not as much energy available for steam generation as in straight refuse burning and the radiation chamber is relatively small.

Change from Refractory to Water-tube Wall at Paris-Issy

Figure S-8 shows one of the four boilers at Issy (1965) which incorporated the results of much Parisian and other experience in high temperature steam from waste fuel. The large, open first and second passes seem to be designed to avoid high temperature corrosion problems; yet wall and superheater corrosion have occurred because:

1. These boilers are overloaded by as much as one third.
2. The two open passes are large in volume and in width which may provide less rapid convection heat transfer.

In 1975 the average input rate per operating furnace was 19.1 tonnes/hr (21.0 tons/hr) and in 1976 this rose to 19.9 (21.9). The original design rate was 15 (16.5) which later was increased to 17 (18.7). In 1975 and 1976 the four units operated 86.4 percent and 84.8 percent of the total elapsed time. This high intensity of operation is needed, but it contributes to increased maintenance requirements, particularly because of inevitably higher peak burning rates than the average.

Issy is an excellent example of the historical development of the Martin furnace. A previous section mentioned that Martin was selected in part because both Martin and TIRU would use the Issy plant for development. The following descriptions of stages document some of the results from this cooperative developmental spirit.

Stage 1. Refractory Brick Walls. While the upper first pass through the economizer section (built by CNIM) was water tubed, the furnace or combustion chamber was originally lined with refractory brick. Presumably the lack of combustion chamber gas cooling caused the first pass side wall tubes to fail in 1966 after 5,000 to 6,000 hours. Probably lag was also adhering to the refractory wall. For whatever reasons, the owners decided to change the furnace wall.

Stage 2. Alumina Blocks Surrounding Wall Tubes. As a corrective measure, the boiler tubes were extended down into the furnace combustion chamber parallel to the grate. There are 3 such sloping tubes on each side. They were 70 mm (2.7 in) in diameter, the tube wall thickness was 4 mm (0.2 in) and the spacing was 160 to 180 mm (6.4 to 7.2 in). A specifically shaped silicon carbide block was designed to fit these tubes and used as shown in Figure S-9. These were installed from the ash

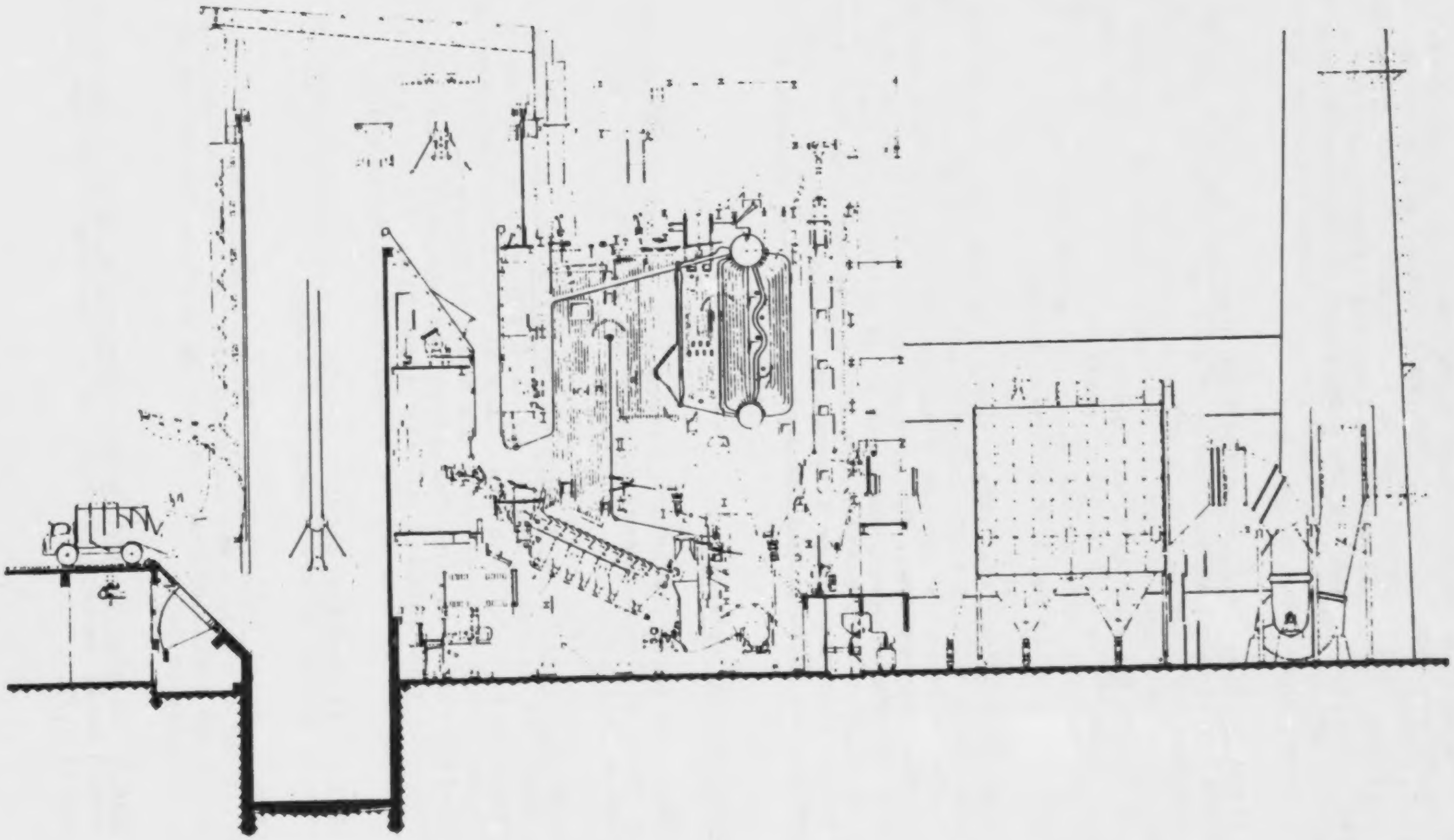


FIGURE S-8. SKEMATIC CROSS SECTION OF THE PARIS-ISSY-LES MOULINEAUX PLANT discharger area up into the first pass above the secondary air jets.

Cement was used to bond the blocks together. While the ash would not easily stick to the special blocks, it did stick to the cement mortar. Eventually in operation or in cleaning, the slag (fused with the cement) would come off--pulling with it the cement mortar. Combustion gases could then penetrate to the tubes. Eventually some blocks began to crack and fall. This system thus had to be replaced.

Stage 3. Plastic Silicon Carbide Surrounding Wall Tubes. The third effort upon removal of the blocks in 1966 was to apply ten (10) tons of plastic silicon carbide to each furnace. A basically dry cement mixture of SiC and 8 percent H_2O was packed and rammed around the tubes as shown in Figure S-10. The material used was Carbofrax SiC798B. Two man-weeks were required to install this plastic material. It should have lasted 5 years. The ash and slag stuck to the walls and would fall when the walls were cleaned. The plastic had little firm anchorage.

Stage 4. Studded Wall Tubes Covered with Alumina. The fourth and current stage uses welded studs covered with 42 percent Al_2O_5 plastic refractory. The alumina is cheaper than the silicon carbide and bonds better at lower temperatures. The more expensive SiC has better wear once a proper bond is made. However, sometimes it is difficult to heat it for a long time at high enough temperature for a complete bond. Wall life has been much better with the Stage 4 approach. During scheduled downtime, more refractory is added around the studs in loosened, cracked, or fallen areas.

Walls of First and Second Passes

These two empty radiation passes have volume of 290 m^3 (10,234 ft^3). The walls of these passes have suffered from tube wastage in limited areas as follows:

Stage 1. Original Bare Water Tube Walls. Originally the wall tubes were bare. The diameter was 70 mm (2.8 in) with a 4 mm (0.15 in) wall thickness. After 15,000 hours, many of the tubes had severe metal wastage or burst. Thin or burst areas are shown in Figure S-11.

Hypothetical reasons for metal wastage vary from (1) flame impingement, (2) overheating of ash deposits, (3) alternating reducing-oxidizing atmospheres to, (4) abrasive particles in gases.

Stage 2. Protective Shields Around Water Wall Tubes. Steel shields were then applied to these sensitive areas.

Stage 3. Metal Deflector Baffles in Second Pass. Because the superheater in the third pass was suffering erosive metal wastage, a metal deflector baffle was installed near the turning point at the bottom of the second pass. (See Figure S-12)

Stage 4. Plastic Silicon Carbide Surrounding Water Tubes in Wall. To further reduce metal wastage, Carborundum's Carbofrax 798B was applied to these areas in 1977.

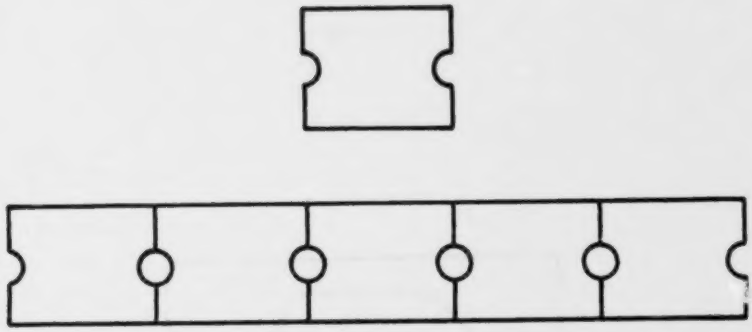


FIGURE S-9. ISSY ALUMINA BLOCKS SURROUNDING BOILER TUBES

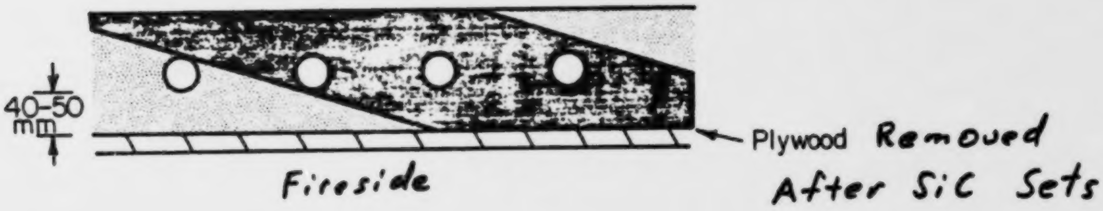

40-50 mm
Plywood
Removed After SiC Sets
Fireside

FIGURE S-10. PLASTIC SILICON CARBIDE SURROUNDING BOILER TUBES

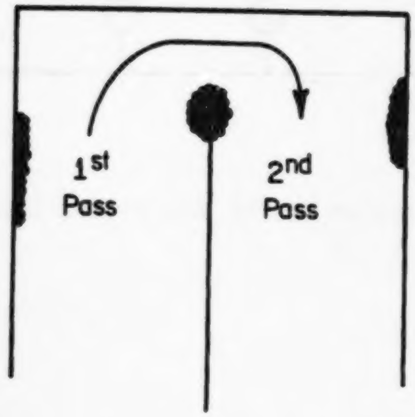

1st
Pass
2nd
Pass

FIGURE S-11. ISSY METAL WASTEAGE ZONES AND AREAS OF CORRECTIVE SHIELDING

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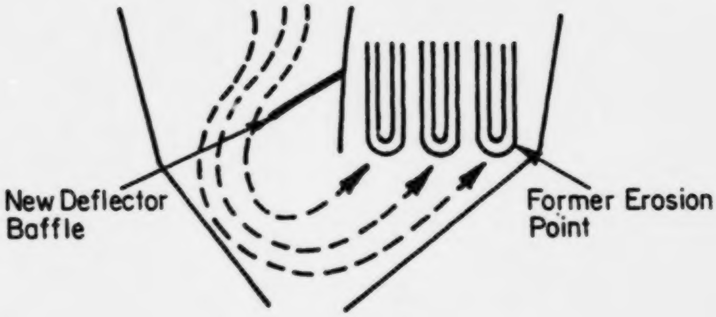

New Deflector Baffle
Former Erosion Point

FIGURE S-12. ISSY NEW SECOND PASS DEFLECTOR BAFFLE TO PROTECT THIRD PASS SUPERHEATER

To sum up the Issy experience, wall tube corrosion in the open first and second passes is being satisfactorily controlled by the use of, shields, and plastic refractory alloy shields.

Wall Tubes at Hamburg-Stellinger Moor Plant

The furnace wall "story" at Stellinger-Moor (S-M) is the most comprehensive and complex of all the plants visited. The plant manager, Karl Heinz Arndt and the control engineering staff is experimentally oriented, open minded and capable of making successful design changes.

Stage 1 (Original Construction). The furnace combustion chamber is fully of water tube wall construction. Depending on wall location, various protective refractories have since been added. The refractory coating of the lower combustion chamber extends upward into the radiation first pass to a level two meters above the front nose. The vertical water tube walls in this combustion chamber are tangent tube construction. The tube outside diameter is 7 cm (2.75 inches) with a 3.2 mm (0.125 inches) wall thickness. The front and rear sloping walls are of welded fin tubes, 57 mm (2.25 in) diameter.

Three water headers slope downward, parallel and near the grate as is shown in Figure S-13.These water header collectors are only near the hotter part of the grate, i.e. after drying and before burnout. Wall thickness tests were made on the west wall on April 22, 1977 after 27,000 hours of operation. The metal wastage pattern is clear. Maximum metal wastage occurred 500 mm (19 in) from the measuring base line at the hottest sidewall portion on the grate. At the worst point, the thickness was still 2/3 of the measuring base line point.

Installing these three tubes on each wall appears to be an excellent method of lowering the localized and very high gas temperatures. These 18^+ mm (0.719 inch) thick tubes will be easier to replace if necessary than the higher-up and harder-to-reach 3.2 mm (0.125 inch) boiler tubes.

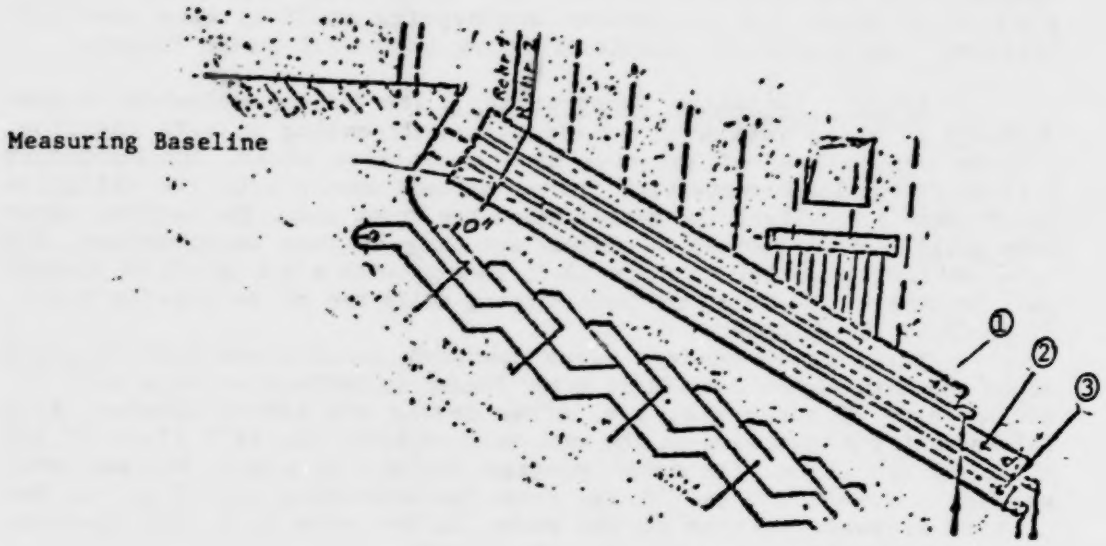
Stage 2 (Simple Addition of Refractory). As time progressed and tubes began to fail up in the boiler, plant officials began to experiment with other measures to directly protect combustion chamber tubes and to indirectly lower gas temperatures entering the downstream boiler passes.

Plant staff supplied a not-to-scale diagram dated October 29, 1976, that shows what had just been done to the combustion chamber. Four refractory materials were used at locations shown in Figure S-14.

Plibrico supplied Plicast 14 (P14) (88-90 percent SIC) to be used above the combustion chamber front roof where the raw refuse enters and down along the sides of the grate where the ash abrades the wall. First, 6 mm (1/4 inch) studs were welded to the tubes at a density of 467 studs per square meter. Then, Plistix 14, a 90 percent Silicon Carbide material, was mixed with water and sprayed on the studded water tube walls.

Also Plibrico Plicast 40 (P40) was used on the hot portions of the studded side water tube walls at a location above the sloping water headers.

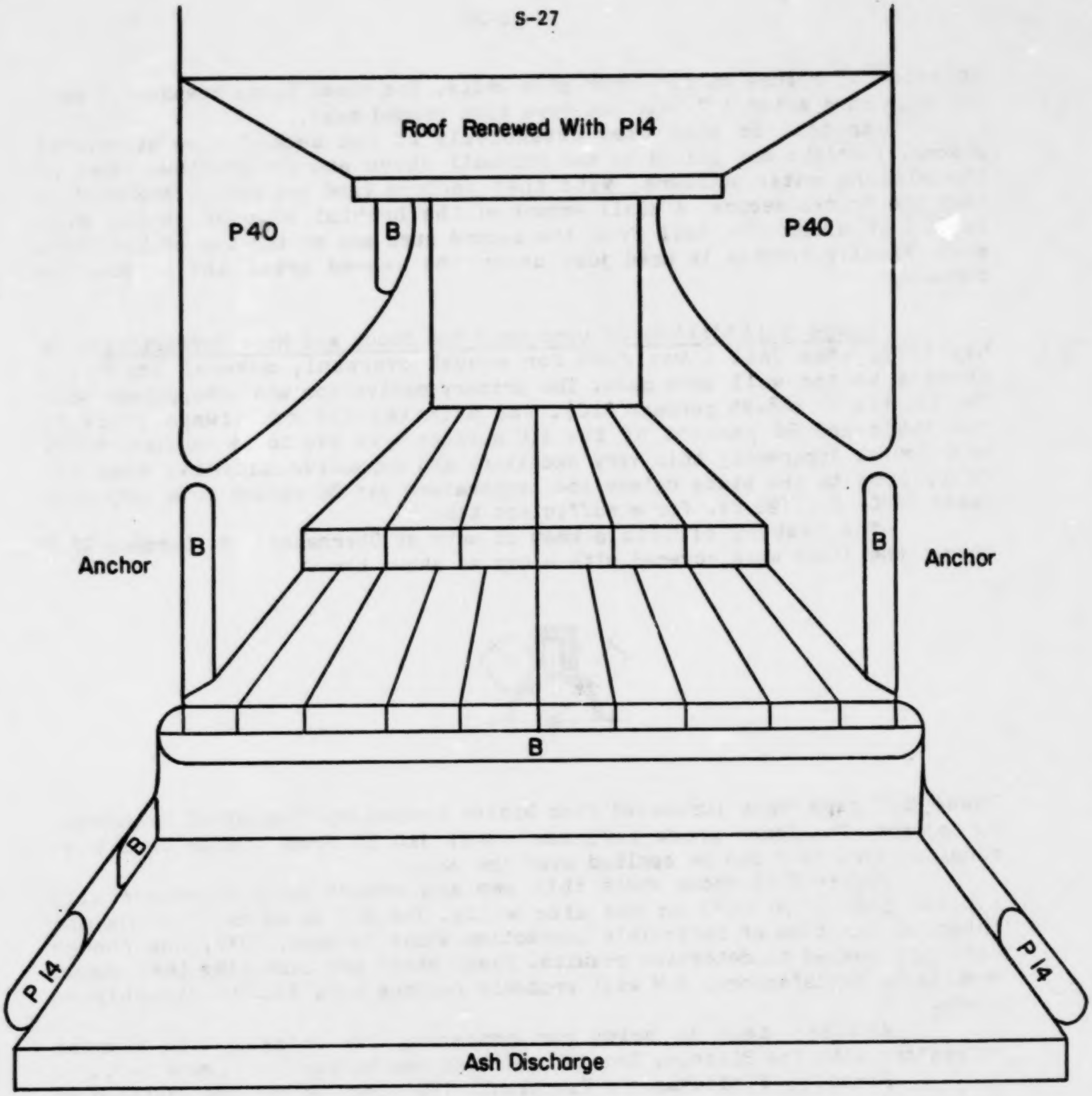
The third material is Brohtal (B) which is 95 percent alumina castable--a preformed brick. An experimental section was installed very near the furnace entrance on only one side to counter the excessive


Measuring Baseline
Rohr 1
Rohr 2
0"
①
②
③

1. Lateral Wall Collector
2. Upper Grate Cooler Beam - Collector
3. Lower Grate Cooler Beam - Collector

Distance (mm)	0	100	200	300	400	500	600	700	800
Wall Thickness (mm)	18	16	14.7	13.5	12.4	11.8	12.1	14.3	16.7

FIGURE S-13. METAL WASTAGE OF WATER HEADERS ABOVE THE HOT SECTION OF THE GRATE AT HAMBURG: STELLINGER-MOOR


Roof Renewed With P14
P40
B
P40
Anchor
B
B
Anchor
B
B
P14
P14
Ash Discharge

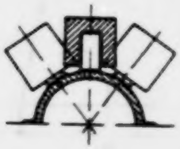
P14	Plistix 14
P40	Plicast 40
B	Brohtal Special High Alumina Castable

FIGURE S-14.. OCTOBER 1976 ADDITIONS OF REFRACTORY TO HAMBURG STELLINGER-MOOR FURNACE #1 abrasion by refuse on the lower side walls. The steel studs themselves were not only bare after 1/2 year but were also eroded away.

Brohtal is also used extensively at the second step at several places. T bricks are placed in the sidewall above and at the lower end of the sloping water headers. Note that anchors (and not studs) are used to keep the bricks secure. A small amount of the Brohtal is used on the side wall just after the fall from the second step and at the top of the third step. Finally Brohtal is used just under the second grate and across the furnace.

Stage 3 (Addition of Caps onto the Studs and More Refractory). In May 1977, when Unit 1 was down for annual overhaul, several important changes to the wall were made. The primary motivation was unhappiness with the Plistix 14 (88-90 percent SiC). The material did not always stick to the studs and 50 percent of the SiC surface area had to be repaired every 4000 hours. Apparently this very excellent and expensive material does not fully bond to the studs unless the temperature can be raised to a very high level 1200 C (2192 F), for a sufficient time.

The Hamburg officials knew of work at Oberhausen, W. Germany RFSG where, the studs were covered with a cap as shown here:



These SiC caps were purchased from Didier Refractory Company of Weisbaden, W. Germany. The lower grade (1/3 the cost) SiC 50 from Didier or a high alumina refractory can be applied over the caps.

Figure S-15 shows where this cap and cement were experimentally applied 5m^2 (54.9 ft^2) on the side walls. The SiC is 40 mm (1.57 inches) thick. At the time of Battelle's inspection visit in June, 1977, not enough time had passed to determine results. Plant staff are expecting that should results be satisfactory, S-M will probably replace more SiC 90 directly on studs.

Another test is being run comparing the Brohtal high alumina refractory with the Plibrico Erocist and also can be seen in Figure S-15.

Finally, Fleischmann's Fixoplanit 138 covering has been applied at the second step and under the grate.

Furnace Wall (Radiation First Pass). Vertically rising above the combustion chamber is the open radiation first pass. Unlike the fin tube walls of the lower combustion chamber, these water tube walls are not welded tangentially and have 5 mm (0.2 inches) spacing between 70 mm (2.75 in) tubes.

These unwelded tubes are free to bulge either out or into the radiation chamber depending on the type and intensity of compressive stresses. An apparently improperly positioned and operating rotating wall sootblower, after 6200 hours of operation, eroded a hole in one of these

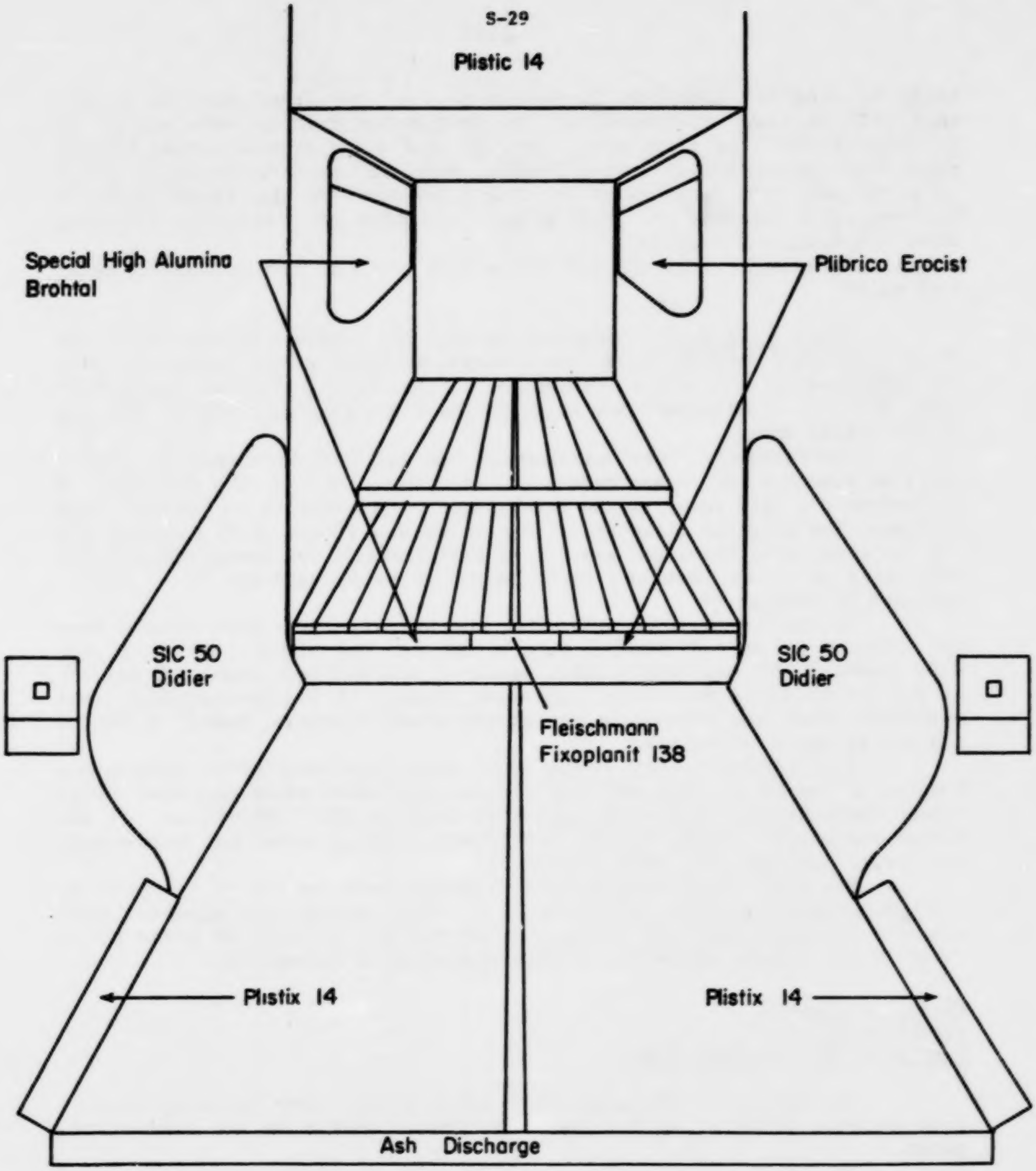

Plistic 14
Special High Alumina Brohtal
Plibrico Erocist
SIC 50 Didier
SIC 50 Didier
Fleischmann Fixoplanit 138
Plistix 14
Plistix 14
Ash Discharge

FIGURE S-15. MAY 1977 ADDITIONS OF CAPS ONTO STUDS AND REFRACTORY TO HAMBURG: STELLINGER-MOOR tubes bulging out into the furnace midway up the first pass. It is felt that, if the lower fin tubes of the combustion chamber were extended further up into the first pass, then the wall could have withstood further abuse from the sootblower before failure. When the one tube failed, another 40 or 50 wall tube sections of thinning thickness were also replaced. There has been metal wastage at other points and once per year, the thinning tubes are routinely replaced.

Stellinger-Moor is one of the last units to have non-welded water tube walls.

First Pass Roof. Some tube wastage has occurred at the top of the first pass where sloping tubes form a suspended roof which continues over the superheater and boiler convection section. These tubes carry saturated steam from the front water tube walls of the first pass directly to the top of the boiler drum.

Fortunately, the management has had the foresight to make a detailed record of all measurements and everything done to the furnaces. A September 21, 1976 entry to the maintenance record reports on the roof tube problems. The original diameter of the tubes was 20 mm (2.75 inches) and the original wall thickness was 3.6 mm (.14 inches). The measurements taken were only on tubes that had shown signs of metal wastage, i.e. tubes numbered 16 through 41.

As can be seen in Table S-1 the thickness had been reduced from the original 3.6 mm (.14 inches) down to between 1.6 and 2.3 mm (0.06 and 0.09 inches). Of the twenty tubes measured, all but two, Number 18 and 39, at 2.3 mm (0.09 inches) were replaced. Number 41 had previously been replaced. When the renovated system was pressure tested, Number 37 failed and had to again be replaced.

The corrosion of these roof tubes was related to incomplete bonding of the SiC 90 that had been sprayed over metal studs on these large tubes. Because the tubes carry saturated steam at 253 C (488 F) and not the hotter superheated steam, the SiC refractory coating never got hot enough for proper bonding, i.e. 1200 C (2192 F).

The plant staff have decided to change from the SiC 90 in favor of a high-alumina plastic refractory. In other words, the superior heat transfer characteristics of a properly bonded SiC 90 will be given up in favor of the cheaper and more reliable high-alumina refractory.

First Pass Outlet (Overflow Tubes at Rear of Radiation First Pass)

The overflow tubes depicted below which carry the steam upward from the wall to the steam drum have experienced erosion by the combustion gases.

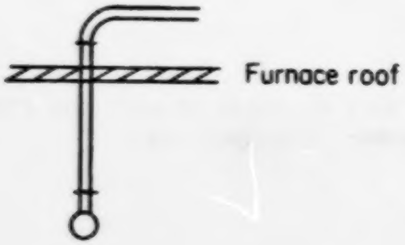


TABLE S-1. WALL TUBE THICKNESS MEASUREMENTS OF SCREEN TUBES AT THE REAR OF THE RADIATION FIRST PASS AT HAMBURG: STELLINGER-MOOR

Tube (Number)	(Boiler Number 1) Metal Thickness (mm)	Action
16	1.8	Tube replaced
17	1.9	Tube replaced
18	2.3	Tube not replaced
19		Measurement not taken
20		Measurement not taken
21	2.2	Tube replaced
22	2.0	Tube replaced
23	2.0	Tube replaced
24	0.0	Ruptured and replaced
25	2.0	Tube replaced
26	2.0	Tube replaced
27		Measurement not taken
28		Measurement not taken
29		Measurement not taken
30		Measurement not taken
31	1.9	Tube replaced
32	1.7	Tube replaced
33	2.0	Tube replaced
34	1.8	Tube replaced
35	1.9	Tube replaced
36	2.1	Tube replaced
37*	1.9	Tube replaced
38	1.8	Tube replaced
39	2.3	Tube not replaced
40	1.6	Tube replaced
41		Was previously changed

* Tube 37 was replaced. It failed under the hydrostatic test apparently due to faulty welding. It was replaced again.

The eighteen (18) tubes are 70 mm (2.76 inches) in outside diameter and 3.2 mm (0.126 inches) in thickness. The maintenance record book of September 8, 1976 shows that tube number 10 failed and caused unit stoppage. Table S-2 shows the results of measurements that showed an uneven pattern of greater metal wastage in the center tubes. As a result the other thin tubes numbered 5,6,9,12, and 13 were also replaced.

In application of the ultrasonic measuring technique, it is recognized that the readings could be in error plus or minus 20 percent. Accordingly if minimum acceptable thickness was, for example, 2.0 mm, anything below 2.5 mm measurement should be replaced. The formula is:

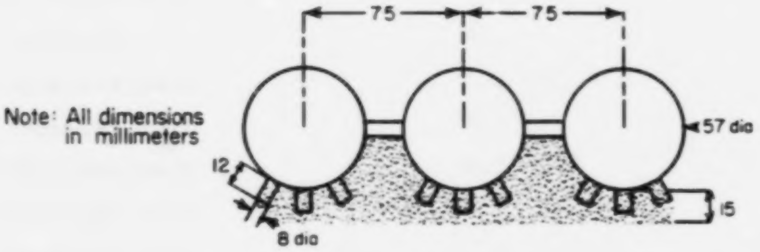
$$X = \frac{2.0 \text{ m}}{1.0 - .2} = \frac{2.0}{0.8} = 2.5 \text{ mm}$$

Fully Water-Cooled Furnace at Zurich-Hagenholz

Figure S-16 is a cross section of Unit Number 3 at the Hagenholz plant which was installed in 1973.

The wall tubes are 57 mm (2.2 in) in diameter and are 4 mm (0.16 in) thick. The center-to-center spacing is 75 mm (3 in). In the first pass, the maximum flue gas velocity is 4.38 m (14.3 ft)/second. Following in the second pass, the maximum flue gas velocity increases due to its smaller cross-sectional area, to 6.66 m (22 ft)/second.

The wall construction is termed "welded fin". The fins connecting the tubes are extruded with the tube. The procedure was developed by EVT of Stuttgart. At the factory steel studs are welded to the furnace side of the tubes to a density of 2000 studs/m^2 (186 studs/ft^2). The stud orientation is radially out from the tube center. Therefore, with respect to the relatively flat wall, the stud angles are different and result in a better anchoring matrix as shown below:



After the studded tubes had been installed at Hagenhholz, plastic silicon carbide (SiC) was placed over the studs to a thickness of 12-15 mm (0.5 to 0.6 in). The use of studs covered with SiC is only in the

TABLE S-2. WALL TUBE THICKNESS MEASUREMENTS OF SCREEN TUBES AT THE REAR OF THE RADIATION FIRST PASS AT HAMBURG: STELLINGER-MOOR

Tube (Number)	(Boiler Number 1) Metal Thickness (mm)	Action
1	3.3	
2	3.3	
3	3.3	
4	2.8	
5	2.4	Thin and replaced
6	1.8	Thin and replaced
7	2.5	Thin and replaced
8	2.9	
9	1.8	Thin and replaced
10	0.0	Ruptured and replaced
11	2.7	
12	2.2	Thin and replaced
13	2.3	Thin and replaced
14	2.8	
15	2.7	
16	2.8	
17	2.9	
18	2.9	

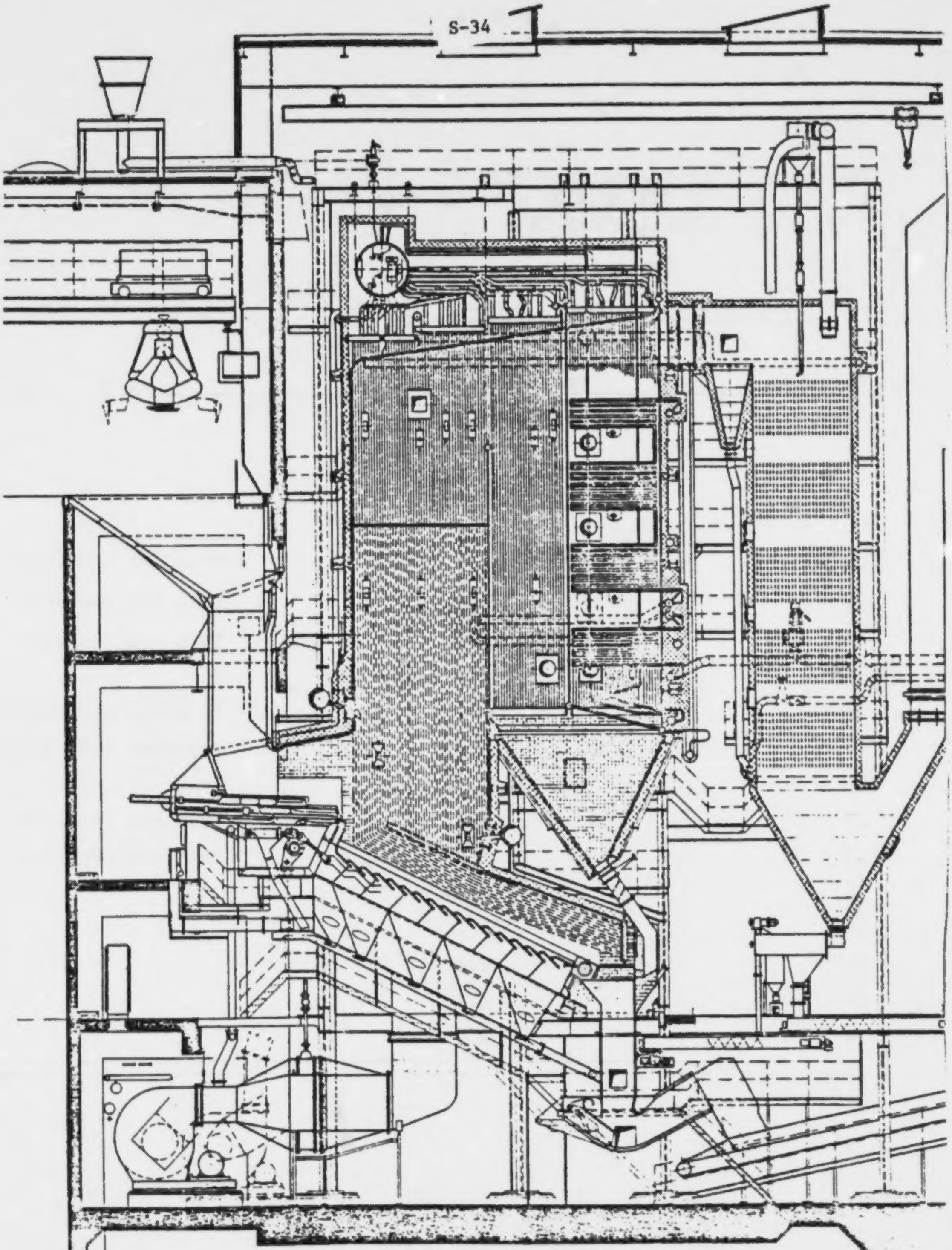


FIGURE S-16. FURNACE/BOILER CROSS-SECTIONAL VIEW OF THE ZURICH: HAGENHOLZ UNIT #3 combustion chamber and the lower 2/3 of the first pass as depicted in Figure S-16. Mr. Baltensperger commented that the SiC should extend one or two meters beyond where flames might be expected.

Figure S-17 is a picture taken of the studded SiC-covered walls taken from across the active combustion chamber in Unit #3. As can be seen, slag very seldom adheres to the SiC. Small amounts of slag will accumulate but will fall off.

Sootblowers are not used in the first and second passes so that any chance of a sootblower malfunction causing a tube rupture is eliminated.

After 30,000 hours, the combustion chamber wall tubes have experienced only 0.1-0.2 mm (0.004 to 0.008 in) metal wastage. This is one of the best wastage experiences in the world.

Two-thirds up the first pass (where the SiC stops), the flue gas temperature falls to about 800 C (1472 F). Because of the relatively high thermal conductivity of the SiC coating, absorption from a heat release rate of 120,000 Kcal/m^2-h (19,000 Btu/ft^2-h) is feasible based on a heat input rate of 48.3 Gcal/hour (191.2 M Btu/h).

The SiC surface is rarely repaired on the 1000 hour inspections but is occasionally repaired on the 4000 hour planned inspections. Studs and SiC are repaired once per year during major overhaul.

Plant staff observed that to reduce wall tube corrosion the vertical man-hole doors should be flush with the inside surface of the furnace wall. Eliminating the recessed cavity will reduce gas impingement and erosion by flyash as shown.

Refractory Furnace Wall at the Hague

In terms of predominant current practice for large furnaces, The Hague plant built in 1968, is noteworthy in that the furnace sidewalls are not water-cooled. What water-tube walled surface is used begins above the furnace and extends from there upward to the top of the radiation chamber (first boiler pass). The sloping rear roof of the furnace is water-cooled but the tubes are completely covered by formed refractory block supported between the tubes. Thus, there is very little cooling of the predominantly refractory furnace. The furnace sidewall construction consists of one layer of high-alumina firebrick plus insulation and a steel casing. The full wall thickness is about 50 cm (20 in). This wall is modified alongside the drying and main grate where the alumina brick is replaced by silicon carbide brick to resist abrasion by moving refuse. This refractory wall has needed little maintenance in nearly ten years' operation. The refractory stops at about the level of the top of the feed opening. A horizontal header for the higher wall tubes is located at that level and the wall tubes extend upward from that level.

At first, in Units 1-3, the wall tubes in the radiation pass were bare. The tubes in Units 1-3 are 63.5 mm (2.5 in) in diameter, 4 mm (0.160 in) thick, on 85 mm (3.4 in) centers and joined by a welded fin. However, within the first year (1969), significant wastage of the wall tubes was observed as well as in the radiant superheater suspended through the top of the radiation pass. Accordingly, that superheater was shortened by 70 cm (2.3 ft) and the wall tubes were studded with 10 mm (0.4 in) long studs and then coated with 12 mm thick (0.5 in) silicon carbide. This coating was carried up to just above the bottom of the shortened superheater.

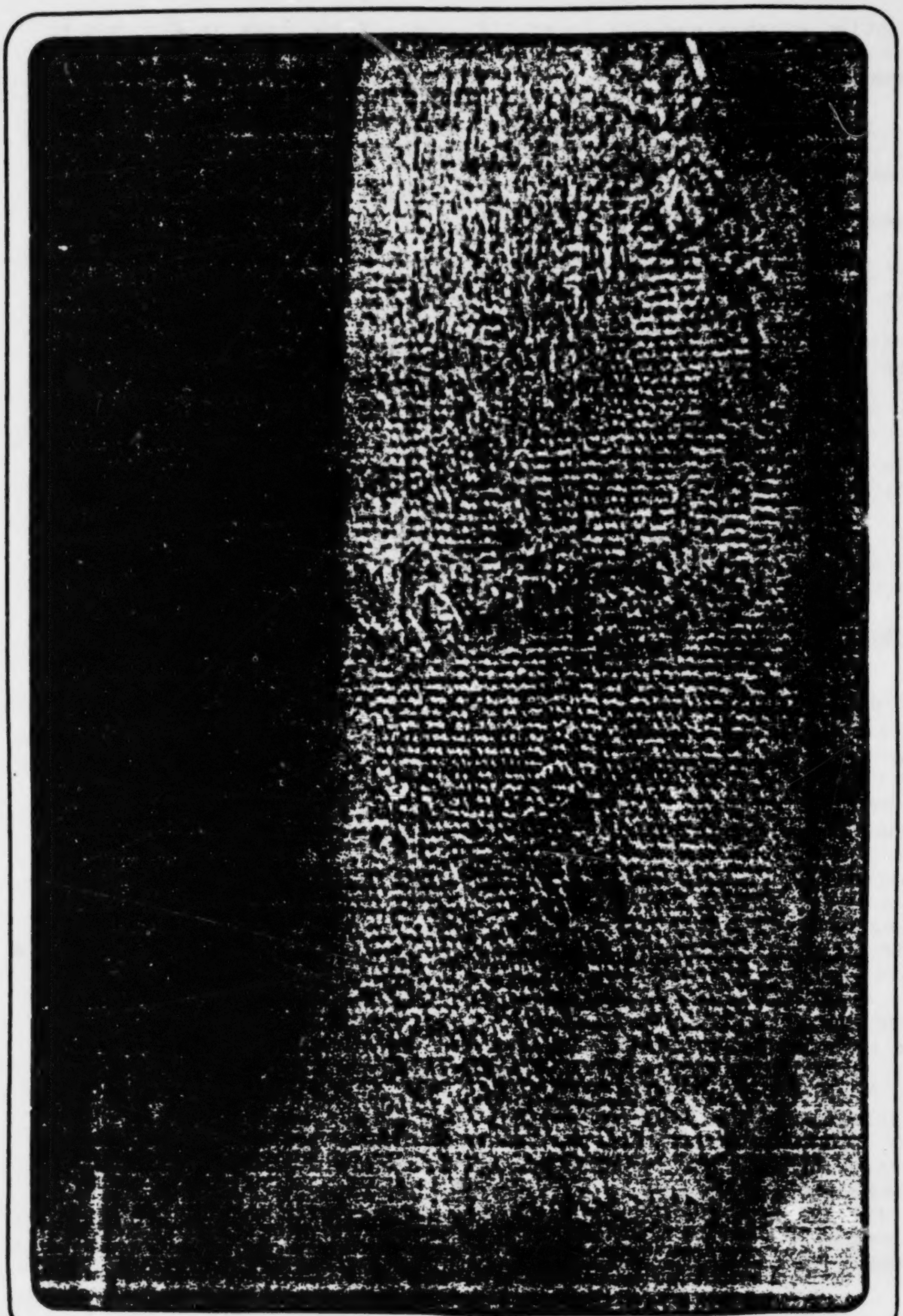


FIGURE S-17. FIRST PASS WALLS COVERED WITH SILICON CARBIDE OVER WELDED STUDS: SHOWS REJECTION OF SLAG FROM WALLS OF ZURICH: HAGENHOLZ (Battelle Photograph)

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best available copy.

Another unique feature of The Hague plant is that it began operation without any overfire air jets. Because of the early corrosion problems referred to earlier, sidewall jets were added.

At first there was little slag accumulation on the refractory sidewalls. However, in 1971 and 1972, after about three or four years' operation, thick acumulation of slag developed on the sidewalls, especially where the burning was intensified when the burning refuse dropped from the drying grate onto the burning grate. Attempts were made to remove this slag mass by means of water lances but this was deleterious to the refractory wall. The thermal shock to the hot refractory wall caused it to tilt inward. Then, continuous air injection was tried along the wall but the build-up of slag continued. It is believed that this growing problem of slag build-up was caused by a substantial rise in the heat value of Dutch community refuse in that period. Relatively high grate burning intensities were probably contributory to the problem.

The solution to the problem of sidewall slag accumulation at that time was to reduce the load on each furnace. Instead of carrying the average daily plant load of about 700 to 750 tonnes per day in two units, each nominally rated at 360 tonnes/day (400 tons/day); the third or spare unit was brought into regular operation so that each unit had to handle only about 230 to 250 tonnes per day (260 to 275 tons/day). However, it is well established that, in this technology, normal wear and tear usually requires a plant to have one spare unit so that each unit in turn can benefit from a planned regular preventive maintenance program. It appears that such considerations led, in 1971, to the order for Unit 4 which began operation early in 1974. The wisdom of this expansion is attested by the fact, mentioned earlier, that the refractory furnace walls of Units 1-3 have required essentially no maintenance except slag removal in nearly ten years' use. Operation of Units 1-3 at reduced rate has eliminated the slag accumulations.

The annual waste input to the plant reached a peak of 229,000 tonnes in 1976. If Unit 4 had not been available that year, Units 1-3 would have been overloaded which certainly would have caused much difficulty in added maintenance costs and reduced availability. Assuming 5-1/2 days per week operation, the 229,000 tonnes burned in 1976 in 52 weeks in three units, (one spare), nominally rated at 360 tonnes/day each results in an estimated operating rate of 800 tonnes/day or 111 percent of rated capacity. Although no mention was made by plant staff of any recent return of problems from sidewall slag build-up, its imminence may have encouraged a decision to plan to install air-cooled Kunstler wall blocks in Unit 2 in 1978.

It is notable that the SiC covering on the studded wall tubes requires little maintenance. During each year approximately four square meters of coating is replaced in each boiler.

Figure S-2a shown earlier, shows, schematically, the arrangement of the air flow through the patented, cast steel, Kunstler blocks which will soon (in 1978) be added on Unit 2. Kunstler of Zurich has added this modified air-cooled wall construction to over a dozen European plants since 1972. It is also not being incorporated into some new plants as original construction. The system does appear to provide relatively cool sidewalls so that sticky slag particles that may touch it are chilled and solidified before they have time to fuse to the wall. The installation in Unit 2 at

The Hague will provide an interesting test of block durability in a large, heavily-loaded furnace.

Figure S-18 and S-19 show a similar wall cooling system using perforated refractory blocks by Didier-Werke AG, Grunstadt, Germany were jointly tested by Von Roll and which Von Roll is now applying at other plants. The installation shown in these figures is at Solingen, West Germany. Less air is required for cooling because the blocks are refractory. Also in case of failure of the cooling air supply the refractory can with stand some overheating.

Refractory Furnace Wall at Dieppe and Deauville

There are two major reasons why the relatively new Dieppe (1971) and Deauville (1976) furnaces are not water-tube walled:

(1) The burning of only partially dried sewage sludge has a cooling effect in the furnace; hence, extensive wall cooling is not needed.

(2) The steam generated for heating the thin-film sludge dryers needs to be only moderate pressure; hence, a much simpler refractory wall furnace and cheaper firetube waste heat boiler can be used.

Accordingly, the only furnace cooling at Dieppe is a diagonal furnace baffle. This baffle is formed of spaced, sloping tubes about 120 mm (4.7 in) apart, which supports bricks shaped to fit the tubes. An estimated 100-150 C (180-270 F) gas temperature drop occurs as the gases flow upward along the underside of the sloping baffle then pass through the spaced tubes above the baffle and turn toward the vertical firetube boiler inlet. It is estimated that about one sixth of the total heat is absorbed by the baffle.

As the gases turn downward around the top of the baffle, they decelerate causing the larger flyash particles to fall out and deposit on the sloping baffle. The buildup of such deposits causes the top-side cooling surface to become ineffective. Also, removal of the accumulated deposit has been difficult. The top and bottom headers for the tubes in the furnace baffle are studded with 40 mm (1.5 in) studs and covered with 80 mm (3.1 in) of Plibrico castable refractory.

At Deauville, designed about 5 years later, there is no water-cooled baffle. The furnace volume 80 m^3 (2823 ft^3)is also much less than at Dieppe. The furnace gases at Deauville pass directly to the vertical firetube boiler.

The main furnace wall at both plants is 500 mm (1.6 ft) thick and is enclosed in a 3 mm thick outer steel casing to minimize infiltration of air. The fireside portion of the wall is built of 65 percent alumina brick. No bricks have had to be replaced except one row of brick in the nose of the front arch after 5 year's operation. Occasionally, broken bricks are patched with Plibrico plastic refractory rammed into place. Explosions of some types of refuse cause some refractory damage and push water out of the clinker quench channel under the furnace. Occasionally, some of the formed bricks in the water-cooled sloping baffle need to be replaced.

The use of refractory instead of water-tube walls entails some loss of thermal efficiency but this loss is not important at either plant so long as there is ample steam generated to dry the sludge.

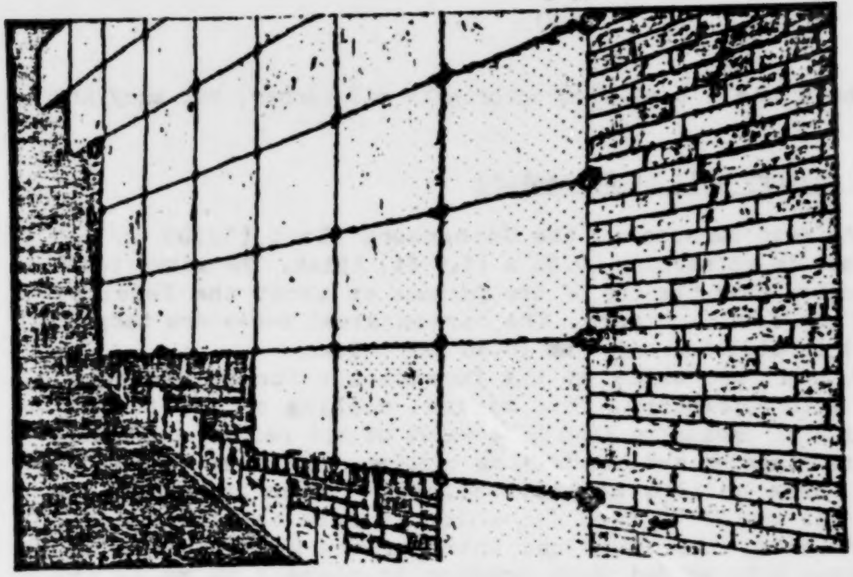


FIGURE S-18. PERFORATED AIR-COOLED REFRACTORY WALL BLOCKS BY DIDIER AS INSTALLED BY VON ROLL AT THE SOLINGEN PLANT, WEST GERMANY (COURTESY VON ROLL)

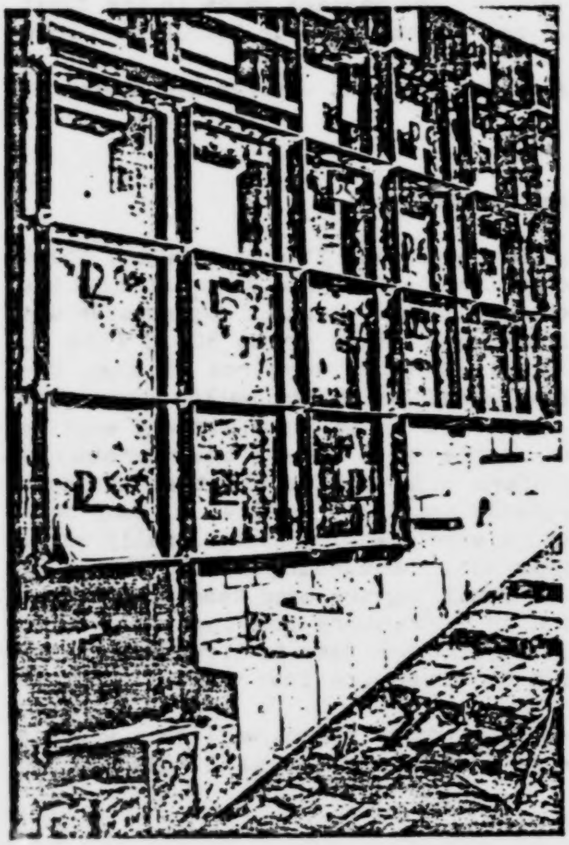


FIGURE S-19. CONSTRUCTION PHOTOGRAPH SHOWING AIR SUPPLY CHAMBERS FOR THE REFRACTORY WALL BLOCKS SHOWN IN FIGURE S-18.

Each furnace has a 6 million calorie/hr oil burner, but they are never used.

Partially Cooled Refractory Wall at Gothenburg

Most of the main furnace at the Gothenburg plant (1970) is not water-tube walled but is refractory, 0.58 m (1.9 ft) thick. The water tubes of the first pass begins near the top of the furnace at about the level of the top of the refuse feed entrance. The carbon steel tubes are tangent welded, 76 mm (3 in) in diameter and 4 mm (0.16 in) thick.

The front and rear walls at the furnace are formed of spaced water tubes covered with refractory. This minimal cooling of the furnace coupled with a period of unusually high heat value of the refuse could have combined to aggravate slagging and overheating problems that have occurred.

Although these boilers generate saturated steam at only 22 bar (149 psia) (1,017 k Pa) and 217 C (423 F), which is well below the usual tube-corrosion threshold, the lower one third of the water-tube walled first pass was equipped with welded studs holding in place a 50 mm (2 in) thick layer of high alumina plastic refractory. This was a successful effort to protect those tubes from chloride attack. However, in July, 1975, immediately above that coating, a tube began to leak in Boiler 2 after 20,830 hours of operation. Three weeks later, a similar leak appeared in Boiler 1. Up to that time, no routine checks had been made of tube thickness. After that experience, checks have been made twice a year at specific locations throughout the boiler. The wastage rates in the first and second passes now range between 0.1 and 0.2 mm per year (0.004 to 0.008 in).

In retrospect, it now appears that the tube wastage was caused by the following:

- High refuse input rates
- High heat value of refuse
- Uneven distribution of air and combustion
- Excessive soot blowing.

Originally, each boiler was equipped with 21 soot blowers. There were two sets in the first pass. Although the plant is for district heating only (hence, does not need high-temperature steam), a small superheater was placed in the third pass to generate superheated steam up to 300 C (572 F) for soot blowing only. When the soot blowers were not in use, the superheated steam was condensed in a heat exchanger in the boiler drum. The soot blowers thus were assured of dry steam so as to avoid any erosive impact on the boiler tubes by water droplets. However, they probably cleaned the tubes too well and too often with the result that the bare tubes were exposed to corrosion and probably erosion. In 1974, it had been first noted that the first pass blowers were cleaning exceptionally well. This increased the possibility for corrosion. Accordingly, 11 of the 21 blowers have now been removed and the 10 remaining are used less frequently.

Another change was to add more refractory coating above that originally installed in the first pass. That was done in three successive steps until the coating extended upward to cover the lower two thirds of the first pass water-tube wall.

Figure S-20 shows another change made to reduce wall tube wastage Eighteen sidewall air jets on each side just below the wall tube header

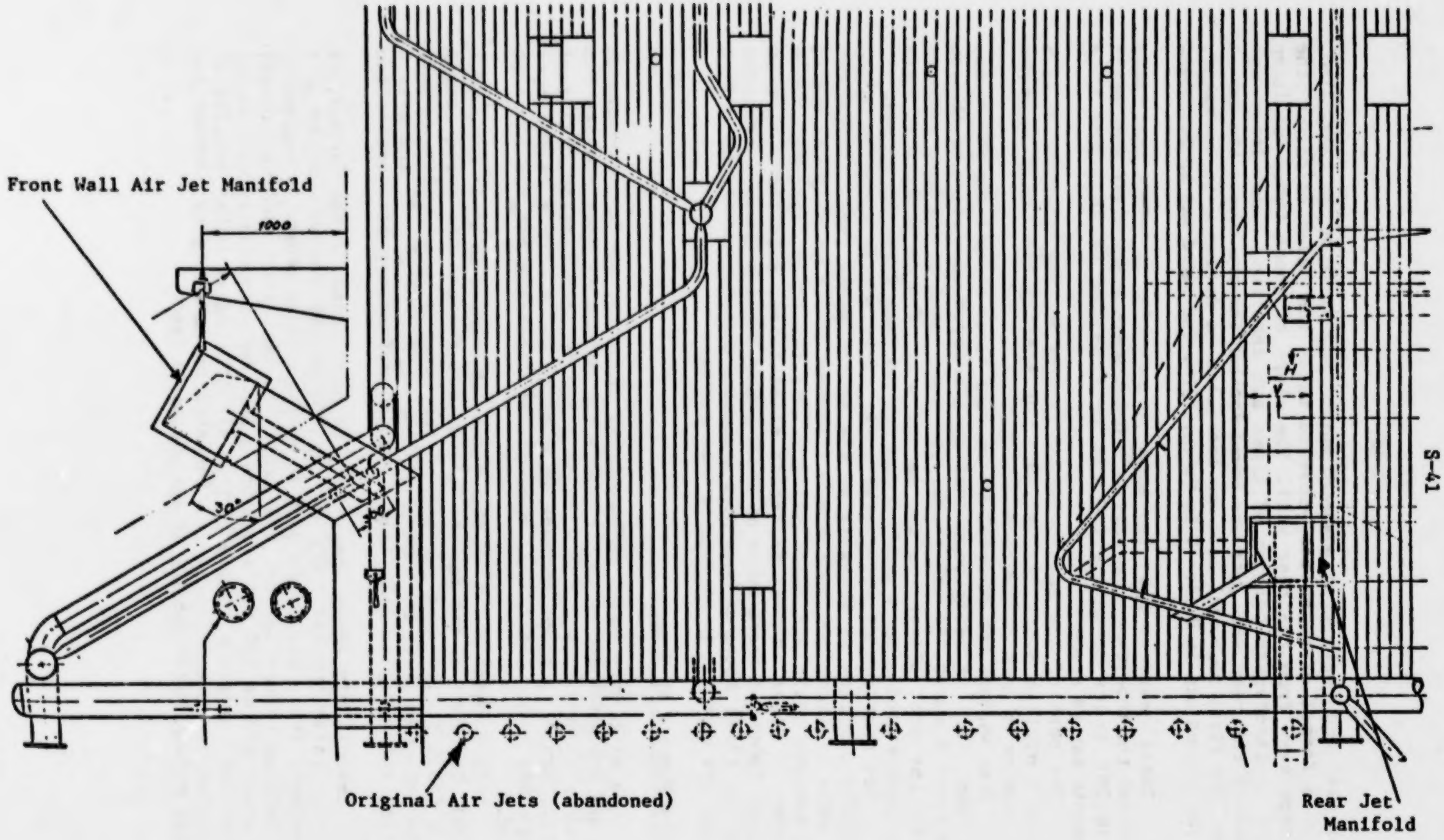

Front Wall Air Jet Manifold
1000
30°
H
Y
Original Air Jets (abandoned)
Rear Jet Manifold

FIGURE S-20. LOWER PORTION OF FIRST PASS SHOWING 18 ORIGINAL SIDEWALL JETS, NOW ABANDONED, REAR NOSE FORMED OF REFRACTORY COVERED BENT TUBES, AND MANIFOLDS FOR NEW FRONT AND REARWALL SECONDARY AIR JETS AIMED DOWNWARD ABOUT 30 DEGREES. (Courtesy GRAAB) were blocked and replaced by downward angled jets in front and back. Also, a rear nose formed of refractory-covered tubes was added to direct the flame flow away from the rear wall. The slope of those tubes was later modified to discourage buildup of loose ash deposits. Also, later the location of the rear wall jets was moved farther forward toward the top of the nose. The first rear wall nose was installed in Boiler 2 in December, 1975. The second was in Boiler 1 in March, 1976. The third was in November, 1976.

These measures plus the apparent reduction in refuse heat value have reduced the tube corrosion rate to a point where plant staff estimates that 30,000 hours of operation can be expected before some tube replacements may be needed.

The cost of the boiler-furnace repairs and modifications in 1975 was about 5 million S.Kr. ($1,140,000). Ordinarily the staff expects overall repairs to cost 10 skr/tonne ($2.07/ton).

Some wastage has occurred in the roof tubes of both the first and second pass. This is being countered by a sprayed-on coating of silicon carbide about 8 mm (0.031 in) thick. The same coating has been sprayed opposite the soot blowers in the second pass. The durability of this coating appears good after 1 year but has not yet been fully determined.

Ten sections of alloy-clad steel tubes are being tried in the upper middle position of the wall of the second pass. These "sandwich" tubes, made by Sandviken, have a wall thickness of 7.1 mm (0.28 in) coated with an extruded stainless steel layer (0.063 in) thick. Although these tubes cost 10 times as much as carbon steel tubes, experience with an entire pass formed of these tubes at the Hogdalen plant built by Vereinigte Kesselwerke (VKW) south of Stockholm indicates that for conditions at that plant they are worth it in minimizing tube wastage.

Refractory Furnace at Uppsala

As with many small refuse-fired furnaces, the four furnaces at Uppsala are not water cooled. Their completely refractory construction has been satisfactory except for a major error in installation (1961) of too-widely spaced support anchors in Furnace No. 4. This caused much breakage and some occasional collapse of firebrick but has now been corrected.

Only Furnace No. 4 in this plant was studied as it is the newest one (1970). The width of the furnace is 2 m (6.5 ft) and the grate length is 8.1 m (16.6 ft). At the far end of the furnace is an offset opening where the hot gases leave the furnace at about 1,000 C (1,832 F) and make a tangential entry beyond into the cyclonic, refractory aftercombustion chamber.

Immediately above the grate, on both sides of the furnace are cast iron plates cooled only by radiation and convection to the surroundings. These plates are used to resist erosion caused by the motion of the burning refuse against the wall. The cast iron surface extends upward about 500 mm (20 in) above the grate. For community refuse, it has been Brunn and Sorensen's experience that air cooling or water cooling of these plates are unnecessary. For furnaces burning highly combustible industrial refuse, water cooling of the plates is used.

Immediately above the cast iron wear plates is a narrow band of silicon carbide brick. These also resist erosion, will stand much higher temperature than cast iron, and have the desirable characteristic of resisting the adherence of molten slag.

The remainder of the furnace wall is built of Hoganas firebrick, tradenamed "Krona", which is rated to withstand 1,600 C (2,912 F). Originally, the first three furnaces were lined with "Chamotte" brick which is naturally occurring clay which becomes a high-grade refractory when fired. However, it is expensive: 14 S.Kr./brick ($2.80 @ 5 Skr/$). All four furnaces are now built of Krona, which costs about 4 Skr/brick ($0.80). The wall thickness for Furnaces 1 through 3 is 1-1/2 brick. Furnace No. 4 is only one brick thick. This causes a higher rate of heat loss which helps prolong the life of the refractory. Some slag adheres to the wall but does not accumulate to great thickness and is considered a protection for the refractory.

At some points, the slag deposit appeared to have been hot enough to flow down the wall but no erosion nor massive slag buildup was evident.

There is no slag accumulation in the aftercombustion chamber following Furnace No. 4.

Refractory Furnace at Horsens

The original plant at Horsens was designed as a hot flue-gas generator for sewage sludge drying in a rotary kiln; hence, the furnace wall is refractory without any heat recovery at the walls. The first meter (3.28 ft) of wall above the grate is formed of korund (45 percent silicon carbide) brick to discourage slag adhesion. Above that, the wall was originally firebrick but now castable or rammed refractory is used.

Originally, the furnace roof was a brick arch resting on steel supports, but because of overheating of the steel, it has been replaced by a poured flat roof of castable refractory supported externally. The new roof was designed by Hoganas using Hoganas "ES" (extra strength) refractory. It is stated to withstand 1,300 C (2,372 F). Its composition is SiO_2--36 percent; Al_2O_3--42 percent; and Fe_2O_3--6.1 percent.

Because the actual refuse fired has a heat value considerably above the design value of 2,000 Kcal/kg, the furnace temperature in early operation reached 1,400 C (2,552 F) instead of the design value of 950 C (1,742 F). Large amounts of plastics were observed being mechanically cut over the pit before placed into the feed chute. This overheated and warped the fire brick furnace wall which has now been replaced by castable refractory. In addition, furnace operation is now slowed to avoid overheating when much "hot" industrial waste must be burned.

Secondary air can be injected through ports in the roof, but these jets are seldom used except just enough to keep the air piping cool.

The refractory after-combustion chamber is 4.25 m (13.9 ft) inside diameter, 3 m (9.8 ft) high on top of a 2 m (6.6 ft) conical refractory hopper. Its intent is to provide gas mixing and burning time and to remove coarse fly ash from the hot gas stream. The CO_2 content of the gases leaving the chamber is in the range of 9 percent.

Originally the furnace exhaust wass cooled by a water spray. An early problem with that arrangement was that some water dripped into the ash hopper causing the ash to harden and stall the discharge screw.

In 1977 the spray cooling tower was replaced by a hot water boiler. Replacement of the spray chamber by the boiler eliminated this problem.

Refractory Furnace for Hot Water Boilers at Copenhagen West and at Amager

Volund furnace walls are refractory lined (and not lined with water tube walls) inside a steel framework.

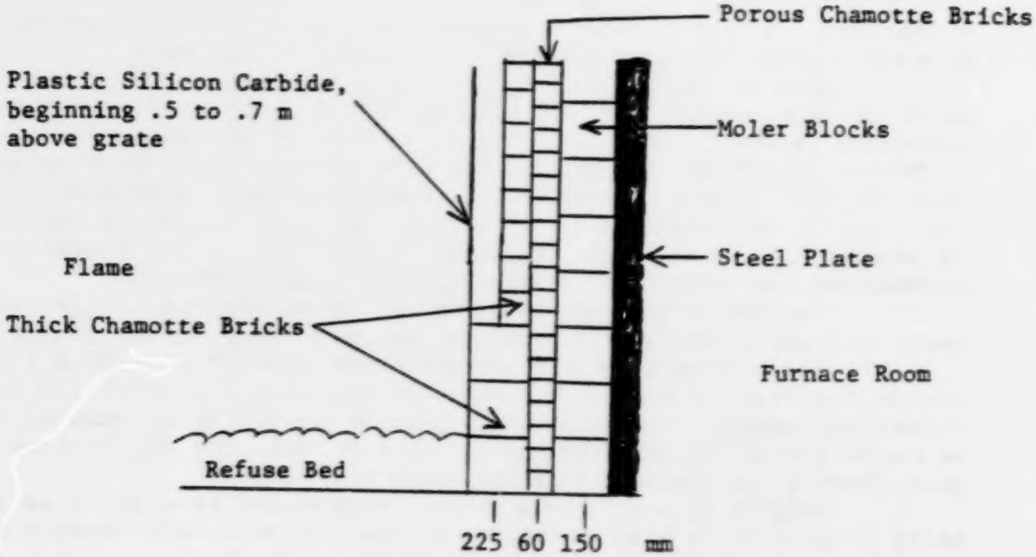
The six furnaces for both Amager and West (three each) were designed and built at about the same time (1970) to supply hot water boilers.

Volund originally chose Hoganas, a high-quality and expensive refractory, for its furnace wall lining. The bricks themselves were not a problem. The difficulty, however, was that there were not enough anchors between the iron structural framework and the bricks. In addition, the few original anchors were not properly welded and broke during thermal expansion. Also, ash was accumulating or "slagging" on the walls.

As a result of the several problems, the furnace walls were rebuilt. Fortunately the warranty period was still in effect. More anchors were added. The anchor welding technique was changed.

To cure the ash slagging problem, silicon carbide was added to the walls above the grate 0.5 to 0.7 m (1.5 to 2 feet). However, where the flame is hottest and the O_2 levels the greatest, the SiC is avoided as it may oxidize. Hence, the lowest wall areas and some of the middle side wall retain the Hoganas chamotte bricks.

Volund officials believe that, with proper anchoring, a refractory wall furnace is less expensive and more reliable than a water tube wall furnace. Having learned from the Amager experience, they now specify a wall shown below:



The Moler blocks near the outside wall are unique to Denmark. The clay is literally quarried or carved out off the deposit in the final shape. (There is no normal mixing and blending of clays.) The blocks are simply fired. The brick dimensions of 23.4 x 11.3 x 6.2 cm (9.2 x 4.5 x 2.5 inches) weigh 1.2 kg (2.6 pounds). This is slightly heavier than many insulating fire bricks but much stronger.

The furnace roof is always arched if the span is less than 3 m (10 feet). However, for wider roof sections, a steel structure is built with many hangers. Specially shaped chamotte bricks are then suspended from the anchors. Then granulated Moler particles are spread on top of the steel and bricks. Finally, rock wool is added as the final insulation.

Rotary Kiln. Most Volund plants provide for only partial burning in the furnace. Mr. E. Blach, formerly Chief Engineer of Volund, described the system as follows:

> "Pre-drying, ignition, and the first part of the combustion takes place on the grate system ... but then the refuse slides into the rotary kiln, where the final combustion and burning out takes place.
>
> While in operation the rotary kiln turns slowly and thus creates a perfect overturning of the burning refuse. The movement makes the refuse travel a very long way and thereby stay for a long time in the kiln. The system operates with the so-called divided flue gas/combustion air circulation, e.g. the primary combustion air is divided into two after having passed through the layer of refuse on the grates, one part passing through the rotary kiln and one part passing over the layer of refuse on the grates up to the top of the furnace, from where it is brought back to the after burning chamber through the previously mentioned connecting flue gas passage coming from the rotary kiln.
>
> Besides primary air, secondary air is added over the grate sections as well as the rotary kiln in order to ensure for certain that the flue gases are fully burned. By adding a surplus of primary and/or secondary air a cooling of the combustion can be achieved, but this cooling function can be achieved better and more effectively by using a flue gas recirculation system, e.g., cooled flue gas is brought back to the combustion zone, over the grates, and at the rotary kiln. While in operation, this cooling function is done automatically so that the temperature is kept at 900° - 1,000° C.
>
> The rotary kiln is built up of an outer heavy steel plate, which is lined with wear resistant fire-proof bricks on the inside. There is an insulating layer between the bricks and the steel plate. The ends of the kiln are furnished with special sliding seals and transition sections. The whole construction rests on two sets of running and guiding wheels. These wheels act as friction pinions, activated by hydraulic motors.

The refractory bricks are anchored onto the steel shell. Moler refractory was originally specified to be placed next to the steel shell. Then next to the Moler refractory, Chamotte bricks of varying alumina and silica content are used to line the inside of the kiln. The brick composition is 85 percent silicon carbide at the inlet.

To some extent, because of very high temperatures, the kiln is self-cleaning. Slag does not normally accumulate on refractory walls. However, at some other Volund plants slag "rings" occasionally form within the kiln. Interestingly, this slag ring can gradually move down the length of the kiln. It eventually disappears.

The grate/rotary kiln design is used for capacities from 5 t/h to about 20 t/h, but can be built also in larger plants.

The carbon steel shell has an inside diameter of 4 m (13.1 feet). Each kiln is 8 m (26 feet) long.

The kiln is sloped downward at a 3 degree angle and revolves upwards of 12 revolutions per hour (rph). Normally it revolves at 6 to 8 rph. If the furnace operator is told by the crane operator that the refuse is wet or if he sees a disturbance in the kiln, he can reduce the kiln speed.

The original configuration had two support rings, two support rollers, one thrust roller, and two drive support rollers all made from high tensile-strength steel castings.

Later, Volund decided that the large spacing between rollers caused excessive compressive forces and alternatively tensile forces to open spaces in the lining depending on where the brick section was on its rotation.

Everytime the furnace is stopped and cooled enough, the kiln is inspected. Occasionally several rings of brick are replaced. Finally in 1977, after 7 year's (42,000 hours) operation, the kiln was completely rebuilt at a cost of 150,000 DKr.

During this major change, the brick used was respecified. Instead of the very porous Moler brick, which was crushed under compressive pressures once per revolution, a harder inner brick was used. Some insulation quality was sacrificed but the temperature just outside the kiln rose only 2 C (3.6 F) from before.

Heat Release Rates

Table S-3 compares the boiler-furnace dimensions and heat-release rates for the 16 plants visited. There are many factors in the individual plant designs which make them exceptional in some way and, therefore, not strictly comparable. However, broadly, the range of volume heat release rates implied in the original designs as shown in this table is instructive.

The highest rates attained were at the Hamburg:Stellinger-Moor, plant which has had to resort to use of water sprays to temper very combustible industrial refuse and also to water sprays in the hot gases to protect the precipitators. This experience does not dictate that lower heat release should be used but it does indicate that ample gas cooling should be provided, not only in the furnace but in subsequent boiler passes.

Nearly as high release rates are reached at Wuppertal and Zurich-Hagenholz and both incorporate considerable water-tube wall cooling surface following the furnace.

All of these plants that have attempted to operate with flame extending to regions of bare wall tubes have, sooner or later, had to stud the tubes annd coat them with plastic refractory. This is distinctly different from coal-burning practice where it is customary to operate with bare tubes throughout the furnace. The important difference is that the

TABLE S-3. BOILER FURNACE DESIGN CONDITIONS

Trip		No. of Boilers	Year Started	Rated Refuse Input		Maximum Refuse Input		Design Lower Heat Value			Steam (or Water) Temperature		Total Design Heat Release per Unit			Combustion Volume		Design Volume Heat Release Rate			Trip
				mt/h	t/h	mt/h	t/h	Kcal/Kg	KJ/Kg	Btu/lb	C	F	Gcal/h	GJ/h	MBtu/h	m^3	ft^3	$Kcal/m^3$-h	KJ/m^3-h	Btu/ft^3-h	Trip
1	Werdenberg-Liechtenstein	1	1974	5.0	5.5			2800	11,724	5040	393	740	14.00	58.5	55.4	142	5012	90,391	412,000	11,060	1
2	Baden-Brugg	2	1970	3.33	3.66	5.0	5.5	2600	10,886	4680	400	752	8.65	36.2	34.3	66	2330	131,000	548,722	14,700	2
3	Duesseldorf Boilers 1-4 Boiler 5	4 1	1965 1972	10.0 12.5	11.0 13.8			1850 2110	7,746 8,835	3330 3800	500	932	18.50 26.37	77.5 110.5	73.3 104.7	170 260	6283 9438	104,000 98,470	435,000 412,300	11,630 11,006	3
4	Wuppertal	4	1976	15.0	16.5			2250	9,421	4050	350	662	33.75	141.3	133.7	184	6498	204,200	854,000	22,990	4
5	Krefeld	2	1976	12.0	13.2			2250	9,421	4050	371	700	27.00	113.1	106.9	171	6038	157,893	661,000	17,747	5
6	Paris: Issy	4	1965	17.0	18.7	19.9	21.9	1800	7,537	3240	410	770	30.60	128.1	121.2	163	5733	187,326	785,170	21,036	6
7	Hamburg: Stellinger-Moor	2	1972	18.8 24.6	20.6 27.1			1800 1500	7,537 6,281	3240 2700	410	770	33.04 36.90	141.7 154.5	134.0 146.1	165	5823	203,090 223,636	850,710 936,320	22,837 25,090	7
8	Zurich: Hagenholz	(1)	1973	21.0	23.1			2300	9,630	4140	420	788	48.30	202.2	191.2	284	10073	170,070	712,030	19,080	8
9	The Hague Boilers 1-3 Boiler 4	4	1965 1974	15.0 15.0	16.5 16.5			1800 2300	7,537 9,630	3240 4140	423	797	27.00 34.50	113.1 144.5	106.9 136.6	232 258	8189 9110	116,379 133,721	487,230 560,000	13,032 14,997	9
10	Dieppe (and Deauville)	2	1971(76)	2.8	3.1			2000	8,374	3600	180	365	5.60	23.4	22.2	80	2823	70,000	293,090	7,905	10
11	Gothenburg	3	1970	12.5	13.8	15.0	16.5	2500	10,468	4500	217	423	31.25	130.8	123.8	263	9301	118,821	497,400	13,323	11
12	Uppsala	(1)	1970	5.0	5.5			2450	10,258	4410	138	309	12.25	51.3	48.5	50	1765	245,000	1,025,000	27,494[2]	12
13	Horsens	1	1974	5.0	5.5			2800	11,724	5040	110	230 (water)	14.00	58.5	55.4	62	2190	225,806	945,400	25,330[2]	13
14	Copenhagen: Amager	3	1970	12.0	13.2	13.0	14.3	2000	8,374	3600	120	248 (water)	24.0	100.5	95.0						14
15	Copenhagen: West	4	1970	12.0	13.2	13.0	14.3	2000	8,374	3600	170	338 (water)	24.0	100.5	95.0						15

[1] There are older boilers in this plant. Only the newest one is considered in this report.

[2] Part of the burning occurs in a cyclonic after-combustion chamber.

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chlorides from refuse burning will attack even relatively cool water tubes if the ash deposit or the tubes is heated by flame impingement. The mechanism involved in this attack is discussed under corrosion. Silicon carbide or alumina coating on studded wall tubes is demonstrating reliable protection from such attack with little maintenance required. The coating does impair heat transfer but additional surface can compensate for that loss.

Many of the smaller plants are demonstrating reliable, low-maintenance operation of completely refractory-walled furnaces. Especially where only low-pressure steam or hot water is all that is needed, the complication of high-pressure, water-tube boiler furnaces are unnecessary. Inherently these plants will tend to recover energy less efficiently than a completely water-cooled boiler furnace connected to a high-pressure steam-driven turbo-generator, but with their simplicity goes also lower first and operating cost. Neverless, in the long run, it appears that rising energy costs will favor the more efficient, more costly techniques.

The successful utilization of very high heat release rates is intimately related to the effective use of secondary air jets to assure rapid combustion within the furnace. This is discussed in a later section.

REFERENCES FOR DATA IN FIGURE S-1

Andritsky, M., "Mullkraft werk Muenchen", Brennstoff-Warme-Kraft, May 1962, 213-237.

Dirks, E., "Ten Years Incineration Plant Frankfurt", Proceedings, Conversion of Refuse to Energy (CRE) Montreaux, Switzerland, Nov. 1975, 580-588.

Feindler, Klaus S., "Refuse Power Plant Technology - State of the Art Review", Unpublished paper presented to the Energy Bureau, Inc., New York, Dec. 16, 1976.

Tanner, Richard, "The Development of the Von Roll Refuse Incineration System", Sanderdruck aus Schweizerischen Bauzeitung, 83 Jahrgang, Heft 16. (1965)

Since this report was drafted the following 2 additional papers have been published which add specific information expecially pertinent to this chapter on Furnace Wall:

Nowak, Franz, "Corrosion on Refuse Incineration Boilers, Preventive Measures", Ash Deposits and Corrosion Due to Impurities in Combustion Gases, R. W. Bryers, Editor, Hemisphere Publishing Co., Washington, 427-436. (Proceedings International Conference on Ash Deposits and Corrosion from Impurities in Combustion Gases, New England College, Henniker, N.H., June 1977.

Feindler, Klaus S., and Thoemen, K.H., "308 Billion Ton-Hours of Refuse Power Experience", Energy Conservation Through Waste Utilization, Proceedings 1978 National Waste Processing Conference, Chicago, May 1978, 117-156, published by ASME, New York, 1978.

SECONDARY (OVERFIRE) AIR

General Comments

All grate-burning of fossil fuels requires overfire air jets above the fuel bed for smokeless, complete combustion.

Mass burning of refuse has very similar requirements. In addition, at very high refuse burning rates in large furnaces, the turbulent mixing provided by jets is of critical importance in assuring complete combustion of the furnace gases before they reach the superheater. If this combustion is not completed well ahead of the superheater, the ash deposits on the tubes can become overheated by the hot, burning gases and tube corrosion can occur as discussed under Corrosion.

As with fossil-fuel practice the application of overfire air jets for mass burning of refuse is still an art and from plant to plant the details of application vary considerably. Some vendors are much more committed to the application of highly intense overfire turbulence than are others.

Principles of Overfire Jets

To abate smoke formation the unburned volatile gases rising from the fuel bed must be mixed rapidly with ample oxygen. If this mixing does not occur promptly the rich gases are very likely to decompose thermally because of the high temperature, thereby releasing fine carbon particles that form smoke and soot.

Because of the principle of prompt and early mixing just described the jets should be relatively near to the fuel bed. But because of the construction of some furnaces this is very difficult to arrange from either the front or rear walls. Accordingly some furnaces are equipped with sidewalls jets so that the jets can be located low in the furnace on a line parallel to the sloping fuel bed. If such sidewall jets are suitably spaced and staggered so that the opposing jets intermingles, mixing can be very effective. However, if the jets are directly opposite each other and are too closely spaced, they have a tendency to drive the flame toward the center of the furnace where oxygen may be deficient. Such an arrangement, then, can cause a longer flame to rise out of the furnace center. A few plants then use tertiary jets located higher up in the furnace wall to make sure that rising tongues of flaming unburned gases are quickly mixed with ample oxygen.

Because of the inherent limitations of sidewall jets just described, many designers prefer front-wall and rear-wall or similarly situated jets, because the main gas flow can often be mixed by such jets without displacing the flame toward the center of the furnace.

In all cases, whether sidewall, front-wall or rear-wall care must be taken to avoid too intense burning in the immediate area around the jet opening. As the jet of air emerges into the chamber at high velocity, 50 to 100 m/s (164 to 328 f/s), it induces rapid inward flow of furnace gases along the wall toward the jet. If this rapid influx occurs in a region of active burning the turbulent flow induced by the jet can cause intense local burning and very high temperatures that can deteriorate either refractory or water-tube walls and can aggravate slagging. If this

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phenomenon is observed, the solution is to reduce the secondary air jet pressure on the few jets involved to a level where the induction effect is minimal.

If such reduced jet velocity then impairs the desired mixing effect in the main part of the furnace, tertiary jets should be considered.

Usually the quantity of overfire air supplied ranges from 10 to 25 percent of the total combustion air, primary plus secondary. Since most furnaces already have ample excess air, the main objective of overfire air jets is to provide good mixing not to add air. Thus additional air is usually less important than turbulence for intense mixing. Thus small jets introducing very high velocity air are usually preferable because this minimizes the amount of air added.

Table T-1 shows the range of jet conditions employed in the plants visited. The following discussion points out the features of each installation and the drastic changes that have been made at a few plants to improve jet performance. The art is still evolving.

Werdenberg-Leichtenstein

Figure T-1 shows diagramatically that at Werdenberg, there are two sets of overfire jets in each sidewall. The upper row of six jets on each side consists of 60 mm (2.36 in) diameter jets in a horizontal row about 5 m (16.4 ft) above the grate to provide air and turbulent mixing where the burning gases pass upward from the top of the furnace combustion chamber to the first open boiler pass. The lower row of 12 jets on each sidewall are 1.8 m (5.9 ft) above the grate and along the inclined line parallel to the grate. The air flow to the jets is modulated automatically according to furnace outlet temperature by a motor operated valve. A high temperature calls for more air to dilute and thus cool the gases.

The overfire air supply is taken from the bunker area. Blower capacity is 30,500 m^3/hr (17,934 cfm) at 20 C (68 F), at a static pressure of 350 mm (13.8 in), total pressure of 385 mm (15 in).

The overfire air supply is taken from the bunker area, Blower capacity is 30,500 m^3/hr (17,934 cfm) at 20 C (68 F), at a static pressure of 350 mm (13.8 in), total pressure of 385 mm (15 in).

The manufacturer states that they prefer front and top (or rear) wall jets over this sidewall jet arrangement and their future designs will not use sidewall jets. The advantages seen from frontwall jets are:

- Better mixing
- Better air distribution in the furnace
- Shorter flame length
- Less carbon monoxide.

Tertiary (Sidewall Cooling) Air Supply

In addition to the overfire air, tertiary air is supplied near the grate through Kunstler cast iron blocks in both sidewalls as shown schematically in Figure T-2in the section on Furnace Wall. This air serves both to cool the cast iron blocks and to provide upward flowing layer of combustion air along the sidewalls for any rich gases that may be burning there. It does not provide turbulent mixing. The air comes not from the bunker but from the furnace room. The forced air is supplied to the back or

TABLE T-1. SECONDARY AIR SYSTEMS

	Date Started	Rated Furnace Tonnes/Hour	Original Overfire Jets: Number of Jets Front	Rear	Sides	Size, Dia. mm	in	Available Air Volume Nm^3/h	Scfm	Max. Available Pressure MmH_2O	in H_2O	Proportion of Total Air Per-cent	Over-fire Air $M^3/^m$ton Capacity	Jet Revisions or Details: Date of Revision	Type of Revision
Werdenberg	1974	5	--	—	18 ea	60	2.36	30,500	17,934	385	15	---	6100	---	2 Levels jets on each side
Baden-Brugg	1970	4.2	--	--	18 ea			15,000	8,820	---	--	---	3570	1974	15-64mm(25in) jets in front and rear; pressure front 500mm (19.7 in) rear 400mm (15.7 in)
Dusseldorf	1965	10	18	20	6 ea			4,000	2,354	280	11	---	400	1967	Secondary air vol. increased to 10,172 Nm^3/hr.
	1972	12.5	18	20	18 ea			15,000	8,828	800	31.5	---	1200	196-	Some jets converted to recirculate flue gas but this was discontinued
Wuppertal	1976	15	30	30	---	50	2	20,000	11,650	800	31.5	—	1333		Actual volume of overfire air used is 60 to 70% installed of capacity
Krefeld	1976				—	—	—			—	—	—		—	
Paris-Issy	1965	17	4	32	—	—	—	72,000	42,336	400	16	20-25	4235	---	The maximum jet pressure is estimated
Zurich:Hagenholz	1973	21	22	22	—	—	—	16,000	9,408	730	29	20	762		No sidewall jets are used because of tendency to push flame toward center
Hamburg:S.-Moor	1972	24	16	16	—	—	—	17,500	10,290	640	25	—	729		
The Hague	1968	15	0	0	0	—	—	0	0	—	—	0	0	1969	9 Sidewall jets 50mm dia were added on each sidewall, 21,000 Nm^3/hr, giving 1400m^3/tonne of capacity
Dieppe	1974	2.5	0	0	0	—	—	0	0	—	—	—	0	1974	Front wall jets were added at Dieppe, 5000Nm^3/hr, giving 2000m^3/tonne of capacity
Gothenberg	1970	15	0	0	18 ea	—	—	33,000	19,420	280	11	—	2200	1976	Sidewall jets replaced by 9, 8mm dia jets in back, 7 in front. Three of the front jets are 150mm dia.
Uppsala	1970	5	--	--	---	--	--	--	--	---	--	---		—	Some primary air is used as secondary dilutive air
Horsens	1974	5	0	--	0	--	--	--	--	250	10	10	--	—	
Amager-West	1970	12	0	0	8 ea	--	--	35,000	20,580	460	18	--	2917		Flue gas can also be recirculated for furnace tempering.

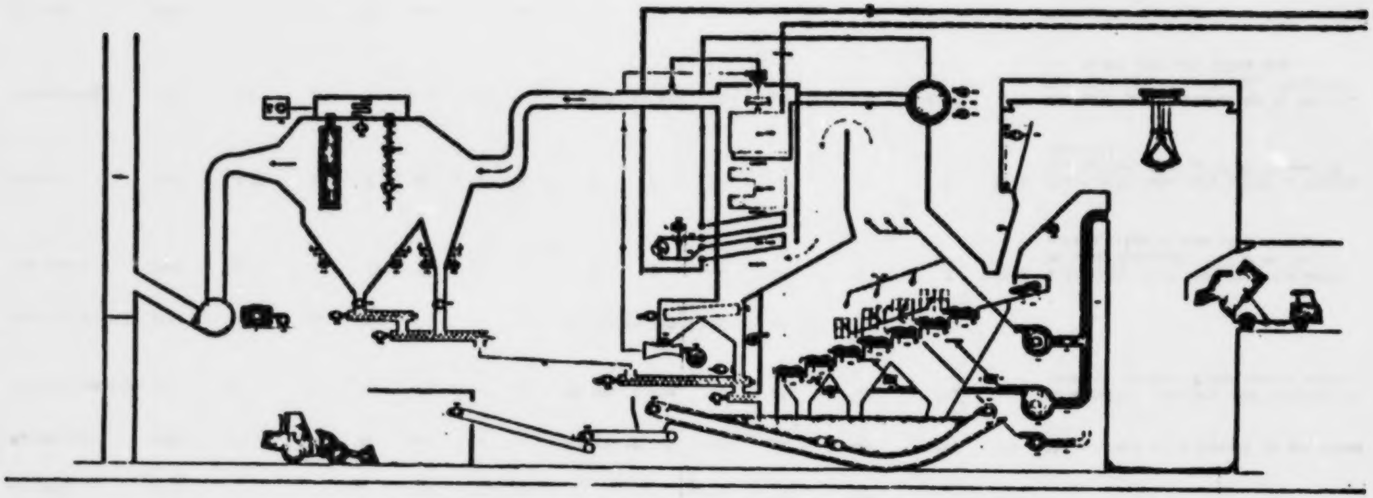

FIGURE T-1. SCHEMATIC VIEW OF WERDENBERG-LIECHTENSTEIN WASTE-TO-ENERGY PLANT, (COURTESY OF WIDMER & ERNST-ALBERTI-FONSAR)

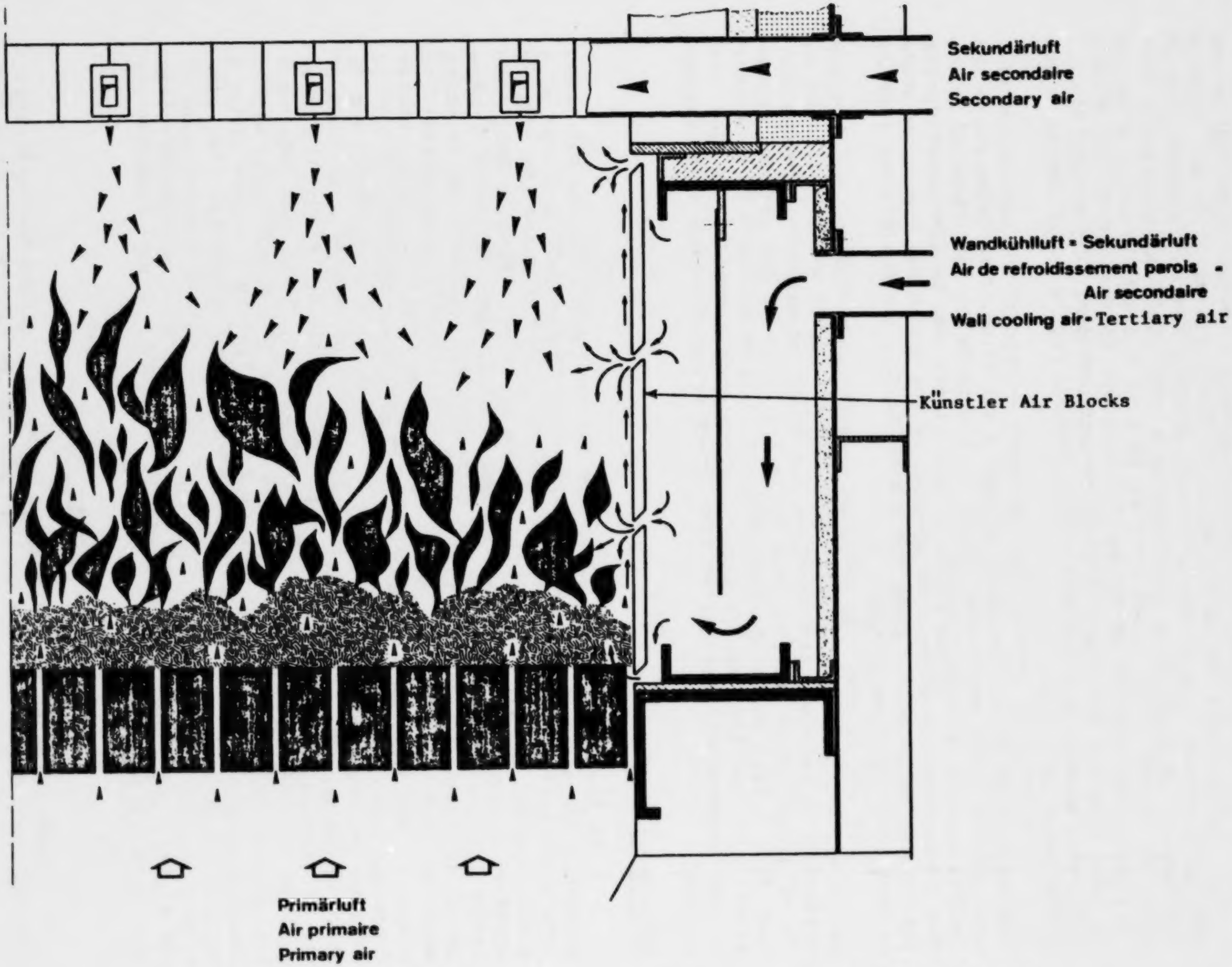
Sekundärluft
Air secondaire
Secondary air
Wandkühlluft = Sekundärluft
Air de refroidissement parois = Air secondaire
Wall cooling air-Tertiary air
Künstler Air Blocks
Primärluft
Air primaire
Primary air

FIGURE T-2. SKETCH OF AIR FLOWS TO FURNACE (Courtesy of Widmer + Ernst) "outside" of the blocks and flows in a generally downward direction behind a steel baffle and then upward until it finds its way into the furnace through the gaps around the periphery of each block. A constant flow of tertiary air is supplied to the blocks by a separately unmodulated blower rated at 12,900 m^3/hr (7600 cfm) at 20 C at a static pressure of 180 mm (7.1 in), total pressure of 190 mm (7.5 in). The 85 cast iron wall blocks on each sidewall are made of 27-30 percent chromium, 0.53 percent nickel, with small amounts of titanium and molybdenum. Figure T-3 illustrates the blocks being installed.

An alarm is sounded in the control room if the temperature of a thermocouple on one of the blocks exceeds a set value. This temperature and that of the steel structure nearby to the plate are both recorded in the control room. At this small plant, no wall blocks have been replaced during the 3 years of operation. Some abrasion of the blocks has been noted where the burning refuse slides along the blocks. So far, the eroded area appears to have lost 1 to 3 mm of iron.

It can be seen that the total capacity of secondary plus tertiary air is 43,400 m^3/hr, substantially more than the 32,000 m^3/hr available as estimated to regulate the overfire air supply to maintain a furnace exit CO_2 of about 9 or 10 percent. This is in the range of 120 percent excess air. From a heat recovery standpoint, it would be desirable to have lower excess air, but this manufacturer's experience apparently is that the higher temperatures associated with lower excess air cause metal wastage problems.

Baden-Brugg

At Baden-Brugg the secondary air is taken from the pit area. Originally the air jets were in both sidewalls, 3 horizontal groups of 6 jets each located approximately one meter (3.28 ft) above the sloping grate. However, as discussed earlier in the section on Furnace Wall, the manufacturer concluded that a principal cause of early failure of 9 tubes in the first open boiler pass was the corrosive action of very hot reducing gases adjacent to those tubes. Also, the sidewall jets appeared to encourage accumulation of slag on the walls. In an effort to achieve better mixing of air and gases the secondary air system was converted in 1974 to front-wall and rear-wall jets, all 64 mm (2.5 in) dia jets. There are 15 jets in the front refractory arch which enter the furnace at an angle of about 45 degrees directly above the first grate section. Figure T-4 shows the 15 jets on the back wall. The blower supplying these rear jets has a capacity of 9000 Nm^3/h (5292 cfm) at a pressure of 400 mm (15.7 in) water. The jets in the front of the furnace are supplied by a blower having a capacity of 6000 Nm^3/h (3528 cfm) at 500 mm (19.7 in) water. The flow rate to each set of jets can be modulated from the control room by means of butterfly valves. The revised jet arrangement has been so satisfactory that the manufacturer expects to utilize only front and rear wall secondary air jets in future designs.

Tertiary Air

Both furnaces are in process of being modified to incorporate side-wall air cooling in the lower portion of the furnace similar to that

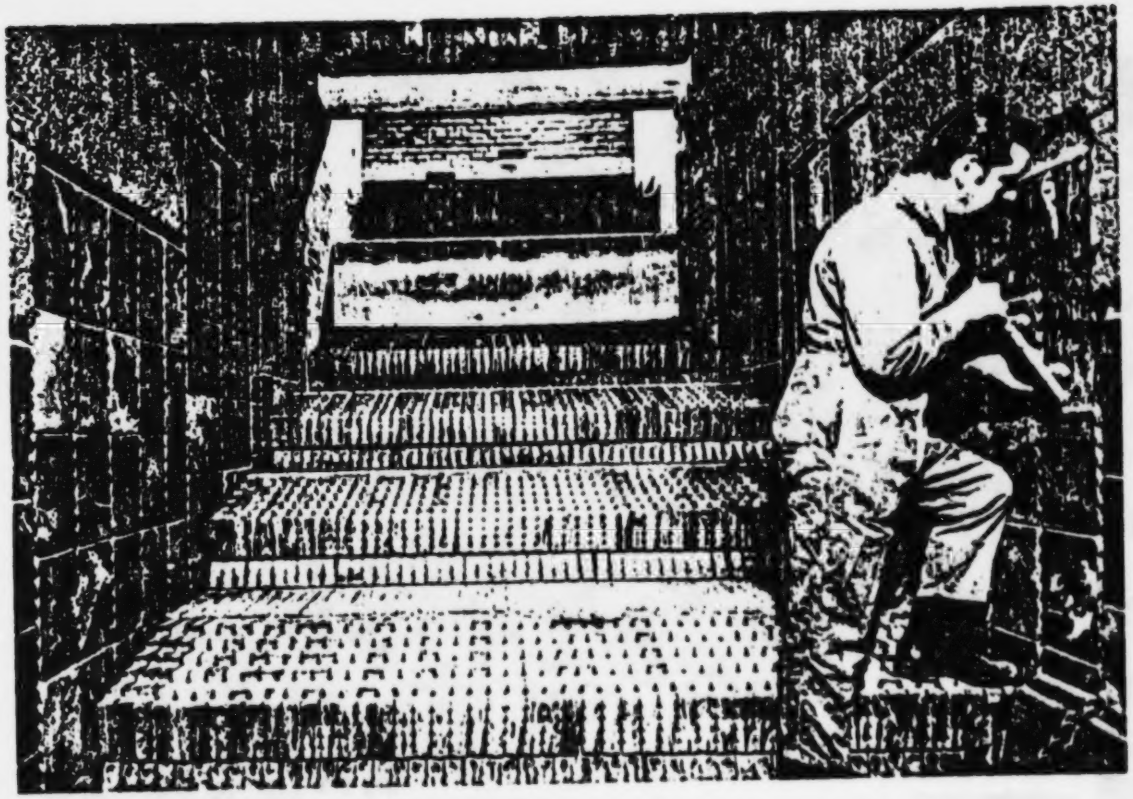

FIGURE T-3. WIDMER & ERNST PHOTO OF MAN APPLYING KUNSTLER AIR-COOLED WALL BLOCKS AT PLANT IN TRIMMIS SWITZERLAND

FIGURE T-4. FIFTEEN SECONDARY AIR JETS OF REVISED SYSTEM IN THE BADEN-BRUGG REAR WALL (BATTELLE PHOTO).

just described at Werdenberg. Figure T-5shows the planned arrangement of 8.5 m^2 (91 ft^2) of air-cooled cast iron blocks to be installed on both sidewalls above the grate. The total air supplied to the blocks will be 6500 Nm^3/h (3822 cfm) at a pressure of 190 mm (7.5 in) water.

Duesseldorf

This plant provides an interesting view of the evolution in the application of overfire air to maintain complete combustion. Apparently the experience with the first small pilot furnace from 1961 to 1965 led the designers of Boilers No. 1-4 to specify only a nominal secondary air flow per boiler of 4,000 Nm^3/hr (2,354 scfm) at a moderate pressure of 280 mm (11 in) water. This air was supplied to a total of 44 nozzles in each boiler distributed as follows:

- 18 pointing nearly downward in the water-cooled front roof
- 20 pointing at an angle down and forward in the water-cooled rear roof
- Six in each refractory sidewall.

As discussed under Furnace Wall, in 1967 an inspection of the water-tube walls in the first open boiler pass immediately above the furnace revealed tube wastage in the front wall which appeared to be caused by the flow against these tubes of high-temperature flame having low oxygen content. To obtain a higher oxygen content at that point, the number of secondary air nozzles was increased. Also, the secondary air pressure was increased from 280 mm (11 in) water to 500 mm (23.6 in) water and the available air volume was increased from 4,000 Nm^3/hr (2,354 scfm) to 10,172 Nm^3/hr (5,988 scfm).

In addition, in 1976, more secondary air was introduced in Boilers No. 1-4 through the air cooled refractory arch or guiding wall which has been described earlier. The air cooling system for this silicon carbide arch has now been evolved to contain 62 air holes in two rows of 31 each. Sixteen of the holes are 30 mm (1.2 in) diameter and 46 of them are 60 mm (2.4 in) diameter. The secondary air flowing into the furnace through this arch cooling system becomes heated to about 200 C (392 F).

Boiler No. 5 has a larger secondary air supply: 15,000 Nm^3/hr (8,828 cfm); and a considerably higher air pressure: 800 mm (31.5 in) water. In addition to nozzles in the front and rear roof similar to Boilers No. 1-4, there are three rows of six sidewall nozzles each, the lowest row about 1.5 m (4.9 ft) above the parallel to the sloping grate line.

These overfire air systems have operated satisfactorily except that at first there was insufficient air supply. In the air piping systems, the individual nozzles have been connected to the air manifolds by flexible steel hoses. Because of overheating some of these connections, they are being converted to stainless steel hoses.

To control furnace temperature at the front where combustion is most intense, some of the secondary air jets were converted to inject recirculated flue gas in Boiler No. 5. However, that causes ash deposits in the piping and requires additional maintenance; hence, will not be repeated in Unit No. 6 which has been designed but not yet built.

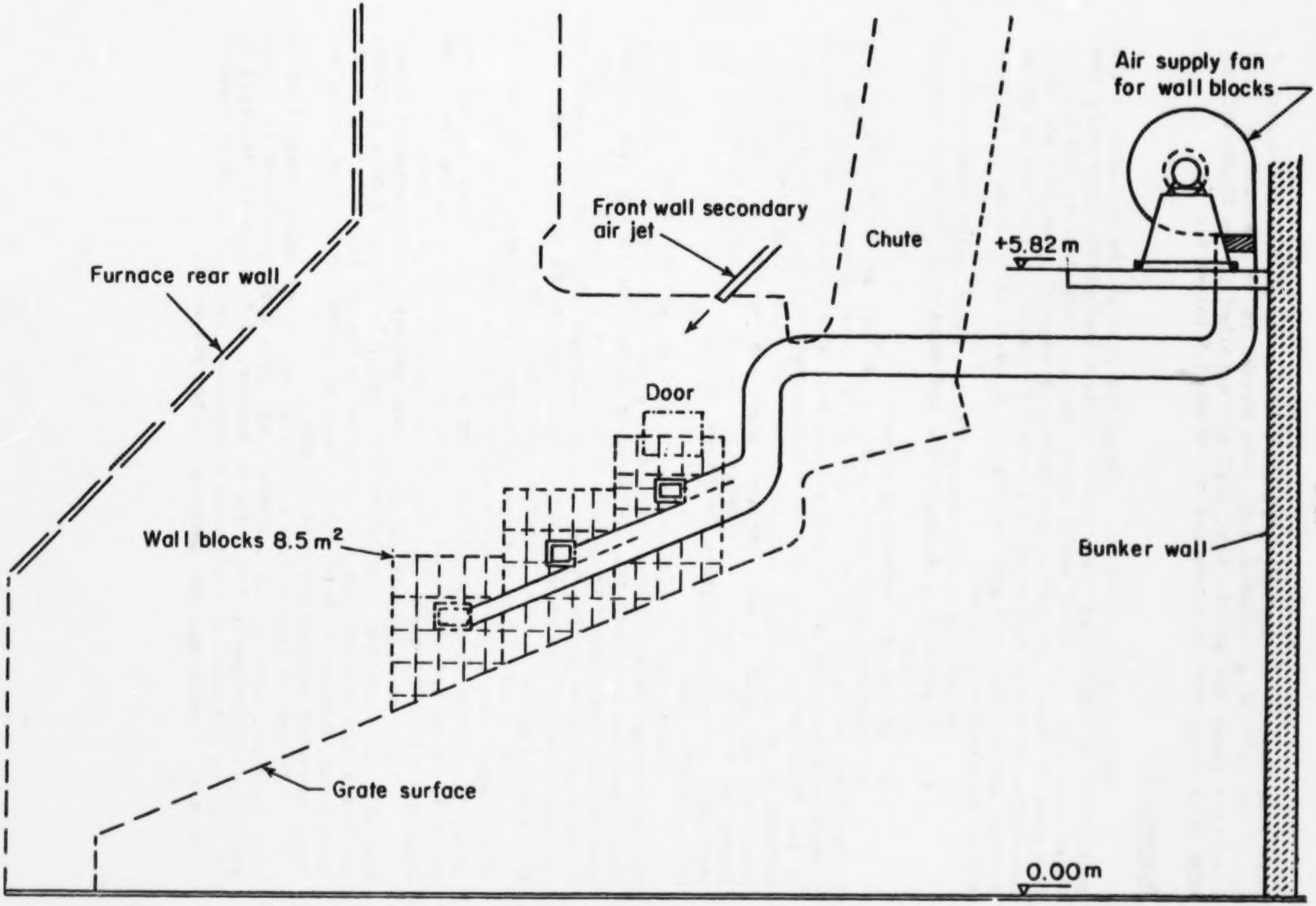
Air supply fan
for wall blocks
Front wall secondary
air jet
Chute
+5.82 m
Furnace rear wall
Door
Wall blocks 8.5 m²
Bunker wall
Grate surface
0.00 m

FIGURE T-5. PROPOSED REVISION OF SIDEWALLS INCORPORATING AIR-COOLED, CAST-IRON, KÜNSTLER BLOCKS (Courtesy Widmer & Ernst) from drawing No. 202076 Dated 9-4-76.

Wuppertal

For the secondary air jets in the 4 furnaces at Wuppertal, one radial blower for each furnace takes air from near the top of the boiler room at a rate of 5.5 m^3/sec (20,000 Nm^3/hr) (11,650 scfm). The available air pressure is 800 mm water static (31 in). This air is supplied to a total of 60 overfire air jets which are 50 mm in diameter (2 in). There are two rows of jets close together in the front wall; and two more rows in the forward portion of the slanting rear wall. All of these jets are directed downward at an angle. The front wall jets are just below the nose of the front wall similar to ones in Figure S-5 under Furnace Wall so that their downward direction provides somewhat opposed mixing to the burning gases rising upward out of the furnace. The rear wall jets are just below the nose of the rear wall and are directed slightly downward into the initial burning zone of the furnace.

Actual air flow ranges from 12,000 to 14,000 Nmm^3/hr (7000 to 8200 scfm). Normally the dampers controlling secondary air are not changed. The plant manager explained that certain other plants also had tertiary air jets positioned half way up in the radiation chamber to try to combat tube corrosion near the top of that chamber but that at this plant, because of the relatively modest steam temperature, 278 C saturated (442 F) at 27 bar (392 psia) and 350 C (662 F) superheated, tertiary air was not believed to be necessary.

Krefeld

The jet arrangement at the smaller Krefeld plant is almost identical to that at Wuppertal. One Buttner-Schilde-Haas radial blower for each furnace supplies air at a rate of 3.8 m^3/sec (13,700 Nm^3/hr) (7,980 scfm). The available air pressure is 970 mm water static (38 in). This air is supplied to a total of 40 overfire air jets which are 70 mm (2.75 in) diameter in the front wall and 50 mm in diameter (2 in) in the upper rear wall. All of the jets are directed at an angle. The front wall jets are in the nose of the front wall so that their downward direction provides somewhat opposed mixing to the burning gases rising upward out of the furnace. The rear wall jets are just below the nose of the rear wall and are directed slightly downward into the initial burning zone of the furnace.

Paris: Issy le Moulineaux

At Issy, the secondary air is supplied by 2 fans, one, having an output of 28,000 Nm^3/hr (16,500 ft ^{3}/min), delivers air to two rows of rear wall jets. Each row has 16 nozzles. Another fan delivers up to 44,000 Nm^3/hr (26,000 ft ^{3}/min) to a single row of four (4) nozzles located 1 to 2 m (3 to 6 feet) above the front wall nose. These 2 secondary air systems together provide 20 to 25 percent of the total air consumed.

The available jet air pressures for the front and rear wall jets are different. The front wall pressure varies from an estimated 200 to 300 mm (8 to 12 in). However, the rear wall pressure varies from an estimated 300 to 400 mm (12 to 16 in).

In the past, there has been some wastage of the nozzles. To minimize such wastage air is flowing through the nozzles at all times. But even with the wastage it has never been necessary to replace any nozzles.

Hamburg: Stellinger-Moor

An unusual feature of the secondary air system at Stellinger-Moor is that secondary air is taken from the primary air system. Most future designs will specify separate systems for primary and secondary air. The secondary air blower capacity is 17,500 Nm^3/hour (10,290 scfm) at 640 mm Ws (25.2 in water) at 30 C (86 F).

There are 16 nozzles in one row above the front wall arch and another 16 nozzles in the rear wall. A damper is used to control the air volume. In Martin's designs in Japan, there are often three rows for secondary air or a completely different tertiary air system due to the high refuse moisture content. Occasionally some of the nozzles need repair due to high temperature scaling of the alloy steel.

One principle in Martin's design to control corrosion is to complete combustion by means of very high secondary air turbulence. In many other plants combustion is more languid. Figure T-7is a photograph of an anonymous furnace that illustrates the rather calm combustion environment observed in so many European and American incinerators.

The shape of the flickering flame and details in the opposite wall are apparent. Such conditions may, at times of high burning rate cause delayed combustion, long flames and resulting boiler tube corrosion.

Figure T-8, taken at Stellinger-Moor however, is entirely different. The three Martin plants visited (Paris:Issy, Hamburg; Stellinger-Moor and Zurich: Hagenholz) all had furnaces of glowing red particles bouncing through the gases and an atmosphere where it was difficult to see the opposite wall.

The available air volumes and pressures at Stellinger-Moor are:

	Maximum Air Volume		Static Pressure		Quoted Pressure		Actual Apr 2, 1977		Actual Nov 4, 1976	
	(Nm^3/Hour	Scfm	(mm,WS)	in,WS	(mm,WS)	in,WS	(mm,WS)	in,WS	(mm,WS)	in,WS
Primary Air	87,000	51,160	530	21	-	-	-	-	-	-
Secondary Air, Front	8,750	5,145	640	25	550	22	400	16	400	16
Secondary, Rear	8,750	5,145	640	25	200	8	520	21	500	20

Usually the pressure at Stellinger-Moor is higher in the front wall nozzles if the heating value is high. The higher jet momentum helps to push the intense flame further down along the grate to spread out the burning over a greater area.

In further designs for Germany and Japan that are concerned with NO$_x$, Martin expects it will have to increase the primary air and lower the secondary air volume.

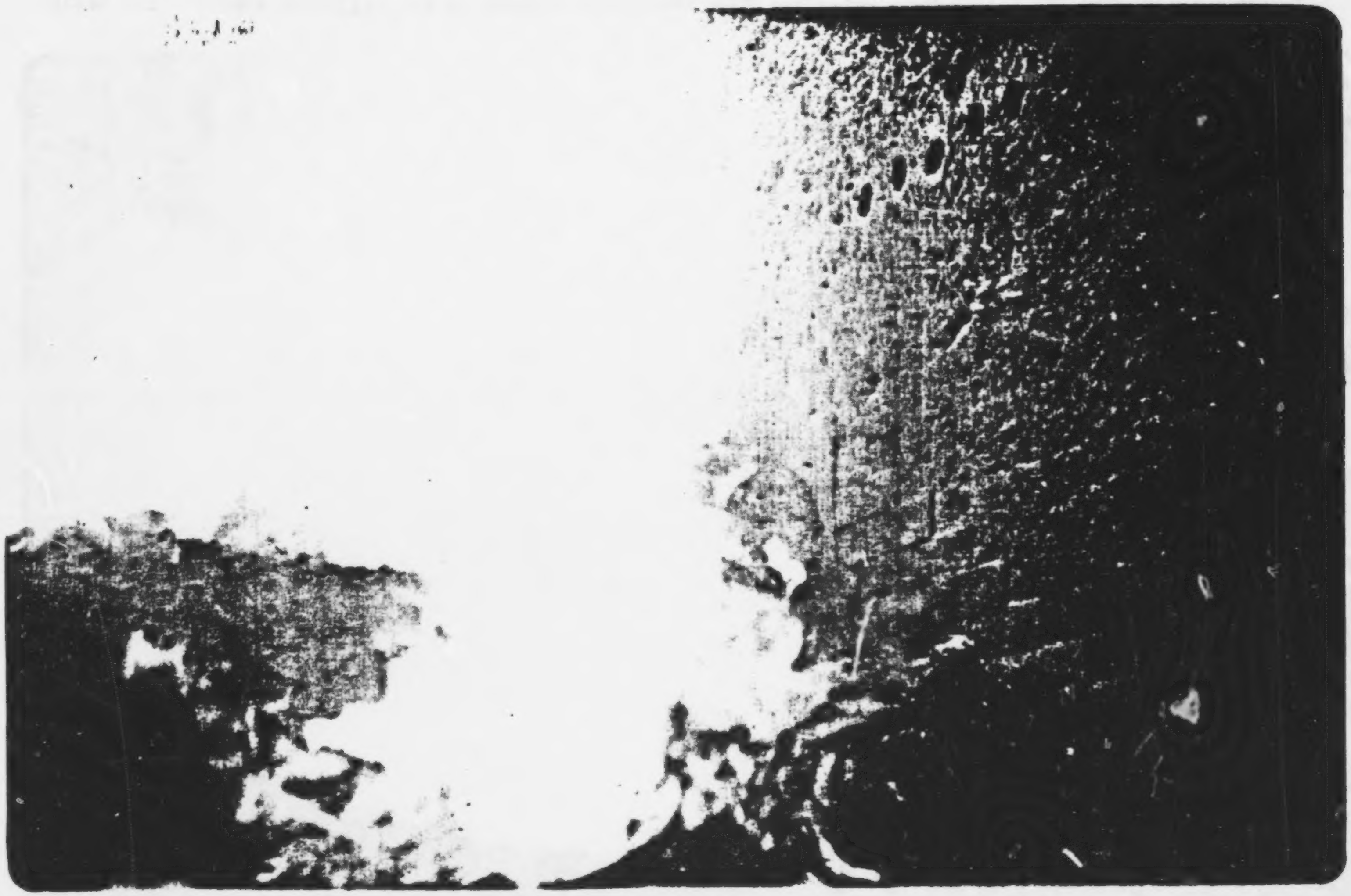

FIGURE T-7. ANONYMOUS FURNANCE WHERE SECONDARY OVERFIRE AIR IS VERY LITTLE OR TOTALLY LACKING

FIGURE T-8. HIGHLY TURBULENT AIR AT HAMBURG:STELLINGER-MOOR RESULTING FROM VERY HIGH SECONDARY AIR PRESSURE

Zurich: Hagenholz

This plant is unusual in that odorus ventilation air from the adjacent rendering plant is the exclusive source of secondary air.

Of the total combustion air, roughly 80 percent is primary air and 20 percent is secondary air. There are a total of 44 air jets equally divided between front and rear walls.

There is no secondary air preheating and the rendering air temperatures average around 20 C (68 F). The maximum air volume is 16,000 Nm^3/hour (9400 scfm). At 730 mm Ws (12 in) while the back wall air pressure is 540 mm Ws (21 in). These relatively high secondary air pressures create high turbulence within the furnace.

Previously Figure T-7 showed an anonymous furnace where secondary air pressure is very low.

Figure T-9 however, shows a highly turbulent condition with no discernable flame shape. This turbulence prevents delayed combustion which according to various corrosion theories, is a possible cause of boiler tube corrosion in RFSG.

The unusual fact is that Zurich: Hagenholz, Martin No. 3, superheaters have experienced only 0.3 mm (0..012 in) metal wastage in 30,000 operating hours. This amazing lack of corrosion exists despite the 732 C (1350 F) flue gas temperature entering the superheater and the 427 C (800 F) steam temperature leaving the superheater. The water tube walls have a most acceptable 0.1 mm (0.004 in) metal wastage for the same time period. This high turbulence along with many other factors share the credit for very low corrosion rate.

Martin and Hagenholz personnel emphasized their rejection of sidewall secondary air jets. Any sidewall jets, they claim, would cause CO formation and long flames to develop in the middle of the furnace. On June 8-10, 1977, the continuous CO_2 records varied between 8.2 percent and 11 percent.

Reliability of the secondary air system has been excellent. The V-belts have not even been replaced after 30,000 hours. The nozzle jets have remained open and clear despite slag buildup on the rear wall.

The Hague

Furnaces 1-3 at the Hague were originally installed in 1968 without secondary air jets. This was consistent with the original design concept for this plant which was expected to be faced with the problems of burning high-moisture, low-calorific-value waste. Thus, the potential cooling effect of secondary air jets was probably deemed of greater disadvantage than any gain that would accrue from the mixing action of air jets.

However, as pointed out in the discussion of wall-tube and superheater corrosion, within the first year of operation, wastage of both areas was observed and it was concluded that the temperatures in the radiation pass (first pass) were, at times, excessive. Accordingly, after one year's operation, nine secondary air jets were added on each side of each of Furnaces 1-3. They are about 50 mm (2 in) diameter and are located in one horizontal row in the refractory sidewall just below the beginning of the water-tube wall of the radiation pass. The jets are supplied with a

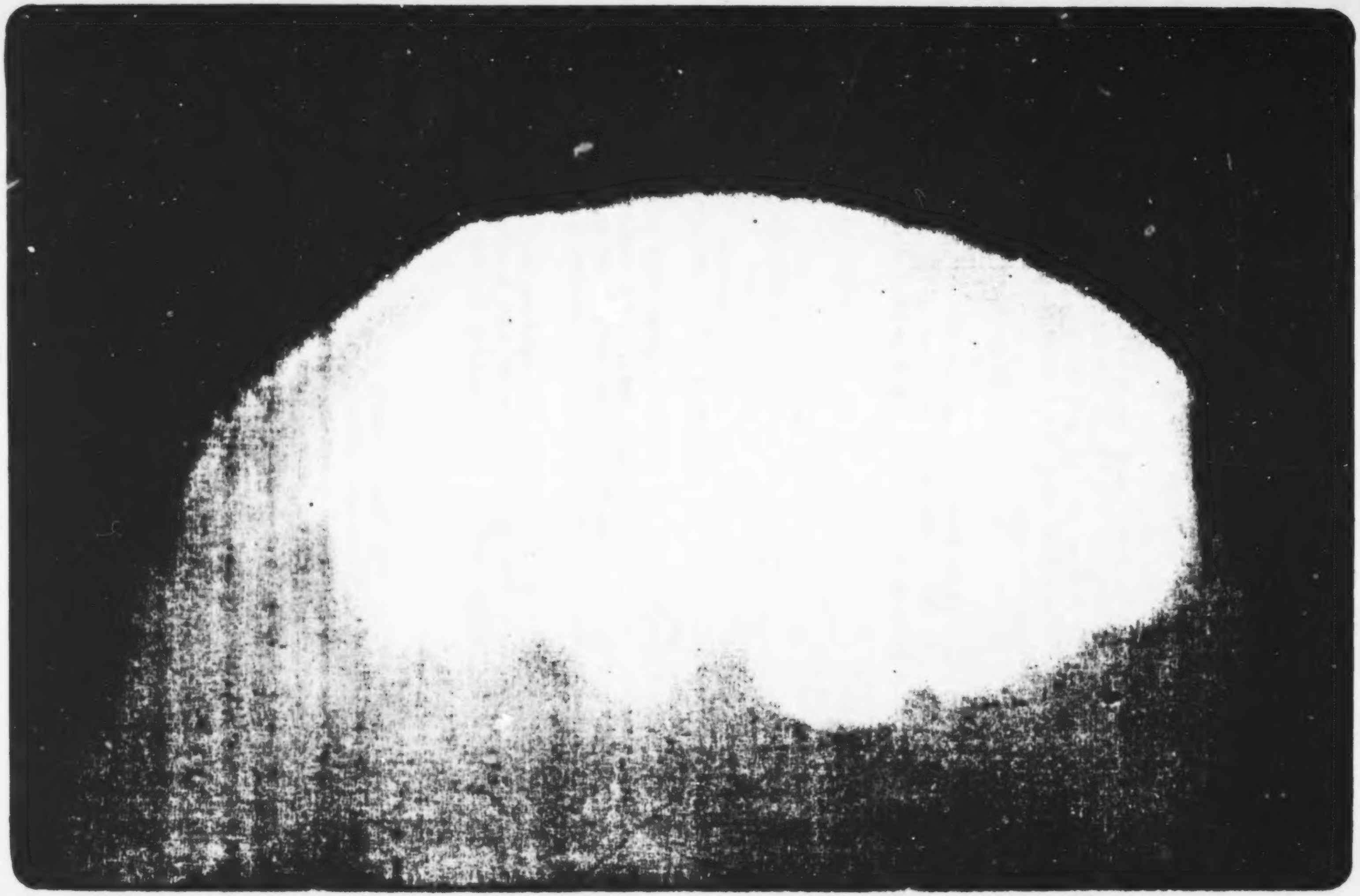

FIGURE T-9. HIGHLY TURBULENT AIR AT ZURICH: HAGENHOLZ RESULTING FROM VERY HIGH SECONDARY AIR PRESSURE maximum of 21,000 Nm_3/h (12,348 scfm) boiler room air by a radial blower producing a maximum static pressure of 390 mm Ws (3834 Pa) 15.4 in water.

When Unit 4 was built, it was supplied with a similar horizontal row of nine jets on each side close to the main burning grate. Figure shows the secondary air manifold on the side of Furnace 4. In addition to the ten jets in the horizontal row there are two additional jet tubes visible on a sloping line at the left. These are directly above the step in the grates between the feed grate and the main burning grate with the slope of line of jets conforming approximately to the slope of the angle of repose of the refuse as it flows into the furnace. A useful detail of the jet tubes shown in Figure T-10is that each tube is lightly capped by a spring-loaded cover which can be easily lifted aside for inspection of the jet and, if the jet entry into the furnace is observed to be clogged by ash or slag, the buildup can be readily poked into the furnace by means of a rod inserted through the tube.

It is not clear whether the addition of these secondary air jets was beneficial. The plant staff appeared to prefer future application of front-wall and rear-wall jets in view of the predominant experience elsewhere that such jets appear to provide better mixing.

The walls of Unit 2 were soon to be modified to incorporate Kunstler air-cooled wall blocks. Presumably, this method of introducing low-velocity secondary air will replace the present wall jets. That furnace may then once more be operating without the mixing action of moderate-velocity air jets. Whether this lack will affect furnace performance remains to be seen.

Dieppe and Deauville

Initially, the refractory furnaces at Dieppe were operated without overfire air but later front-wall jets were added, supplied by a blower with maximum capacity of 5,000 Nm^3/hr (2940 scfm) at 150 mm water (1,470 Pa) (6 in). At Deauville secondary air is injected through six jets in each sidewall.

Gothenberg

At the Gothenberg plant the secondary air blowers can deliver to each furnace 33,000 Nm^3/hr (19,420 scfm) at 250 to 280 mm water (2.54 kPa to 2.74 kPa) (10.2 to 11.0 in). The estimated velocity in the air nozzles is 35 m/sec (115 fps).

Figure T-12shows changes that were made in 1975-76 to reduce tube wastage. The 18 sidewall air jets on each side just below the wall tube header were blocked and replaced by 7 downward angled jets in front and 9 in the back. Fifteen of these jets are 80 mm (3 in) dia. but 3 of the front ones are 150 mm (6 in) dia. Also, a rear nose formed of refractory-covered tubes was added to direct the flame flow away from the rear wall. A sloping dotted line above that rear nose shows how the slope of the tube was later modified to discourage buildup of loose ash deposits. Also, later the location of the rearwall jets was moved farther forward toward the top of the nose. The first rear wall nose was installed in Boiler 2 in December, 1975 (Week No. 48). The second was in Boiler 1 in March, 1976 (Week No. 10). The third was in November, 1976 (Week No. 46).

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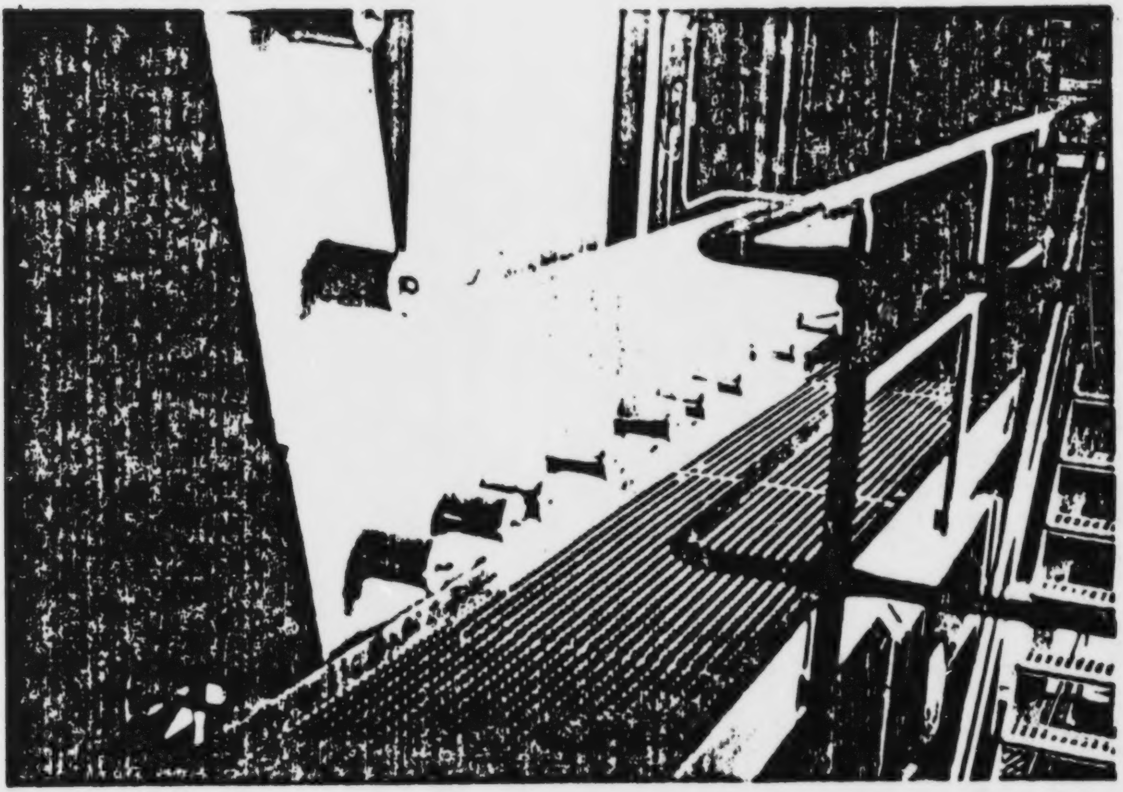

FIGURE T-11. EXTERIOR VIEW OF TUBES FOR SECONDARY AIR JETS ON SIDE OF UNIT 4. TEN JETS ARE SPACED HORIZONTALLY AND TWO ARE LOCATED ALONG A SLANTING VERTICAL LINE AT LEFT. NOTE SPRING-LOADED CAP ON EACH TUBE TO FACILITATE INSPECTION AND CLEANING (Battelle Photograph)

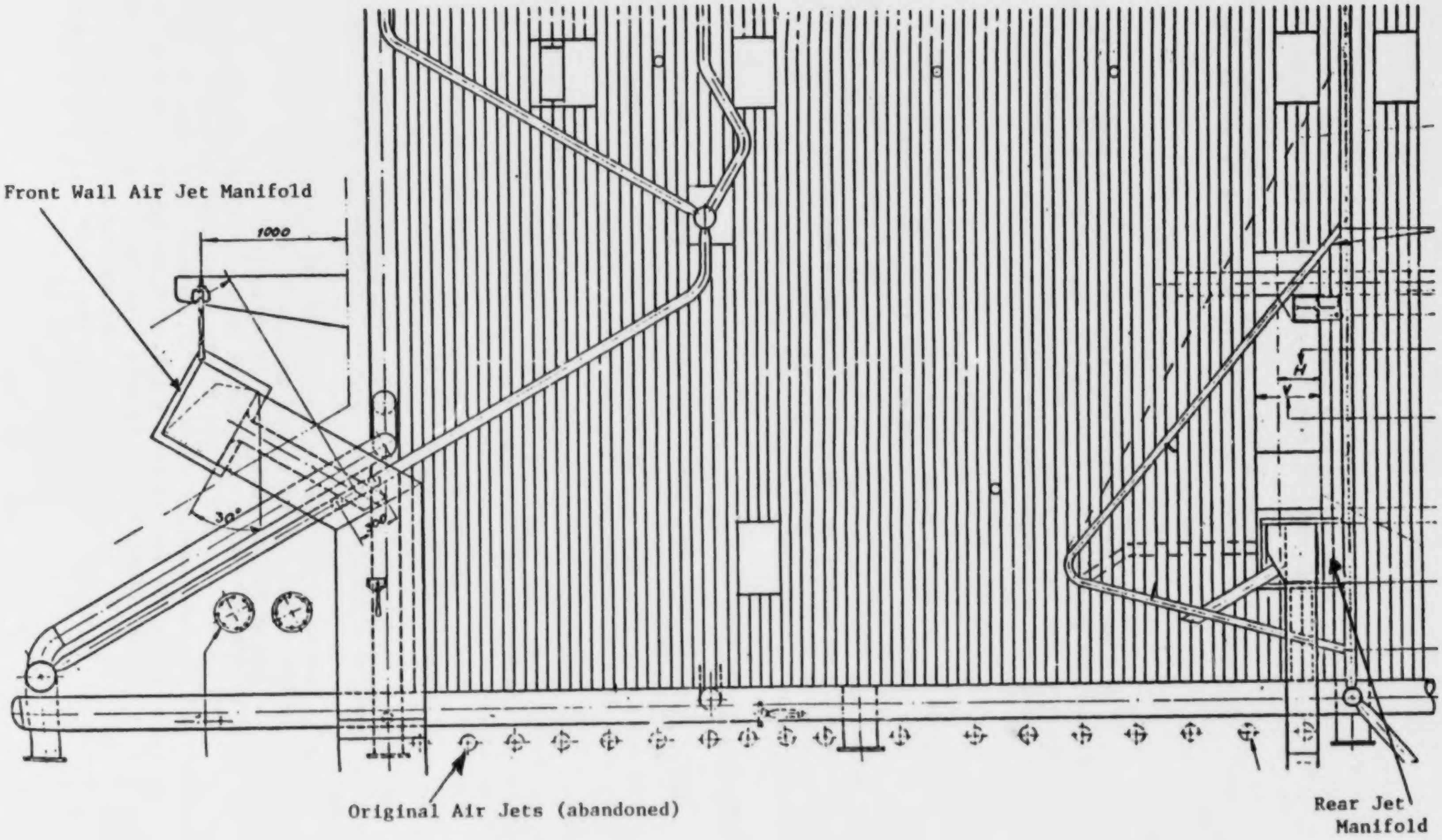
Front Wall Air Jet Manifold
1000
30°
300
H
V
Original Air Jets (abandoned)
Rear Jet Manifold

FIGURE T-12. LOWER PORTION OF FIRST PASS SHOWING 18 ORIGINAL SIDEWALL JETS, NOW ABANDONED, REAR NOSE FORMED OF REFRACTORY COVERED BENT TUBES, AND MANIFOLDS FOR NEW FRONT AND REARWALL SECONDARY AIR JETS AIMED DOWNWARD ABOUT 30 DEGREES. (Courtesy GRAAB)

These measures plus the apparent reduction in refuse heat value have reduced the tube corrosion rate to a point where plant staff estimates that 30,000 hours of operation can be expected before some tube replacements may be needed.

The secondary air blowers take moist air from above the residue quench channel to which, in winter, warm air is supplied from the top of the furnace room.

Uppsala

For all 4 furnaces at Uppsala the secondary air is supplied by the primary air blower. In Furnaces No. 1 through 3, there is only one sidewall jet needed and not for turbulence. In Furnace No. 4, the secondary air is automatically regulated by a smoke density meter.

Horsens

At Horsens, Denmark about 10 percent of the primary air volume is available as secondary air at a pressure of 200 to 250 mm water (7.9 to 9.8 in). This air can be injected through ports in the furnace roof. However, this air is seldom found necessary as sufficient burning time and gas mixing are usually provided by the cyclonic after-combustion chamber which is characteristic of Bruun and Sorensen plants. Hence, usually only enough secondary air flows to cool the roof-ports and connected piping.

Copenhagen:Amager and West

Secondary (Overfire) Air - Boiler Room Cool Air.

Both modern plants at Copenhagen:Amager and West, are equipped with a secondary fan which pulls cool air from the refuse bunker and supplies it to the furnace as overfire air. Both also have hot flue gas recirculation fans.

The Nordisk Ventilator forced-draft 150 Hp belt-driven fan, running at 1,670 rpm, can pull 35,000 Nm^3/hour (20,580 scfm). The temperature is assumed to be 30 C (80 F) and the static pressure is 460 mm water (18 in water).

The air is sent to two manifolds on each side of the furnace and above Grate III. Figure T-13 shows secondary air nozzles.

Secondary (Overfire) Air - Flue Gas Recirculation Hot Air.

During only the first year of operation Amager used recirculated hot electrostatic precipitator.

A 150 Hp motor drove the belt-driven fan at 1,460 rpm. The fan is rated at 45,000 Nm^3/hour (26,500 scfm) and delivered the 300 to 350 C (572 to 662 F) hot flue gas at 220 mm water (8.7 in water).

The use of ambient boiler room air at 30 C (86 F) or recirculated flue gas air, 138 to 177 C (280 to 350 F), is determined by basic furnace design and the refuse lower heating value (LHV). Assume that the furnaces were nominally designed for refuse with a LHV of 2,000 kcal/kg (8373 kJ/kg) (3600 Btu/lb). If the LHV being burned is well over this design value, then cool ambient air, rich in O_2, might shock the refractory and cause the Carborundum bricks to spall. Therefore, if the refuse is "hot", then

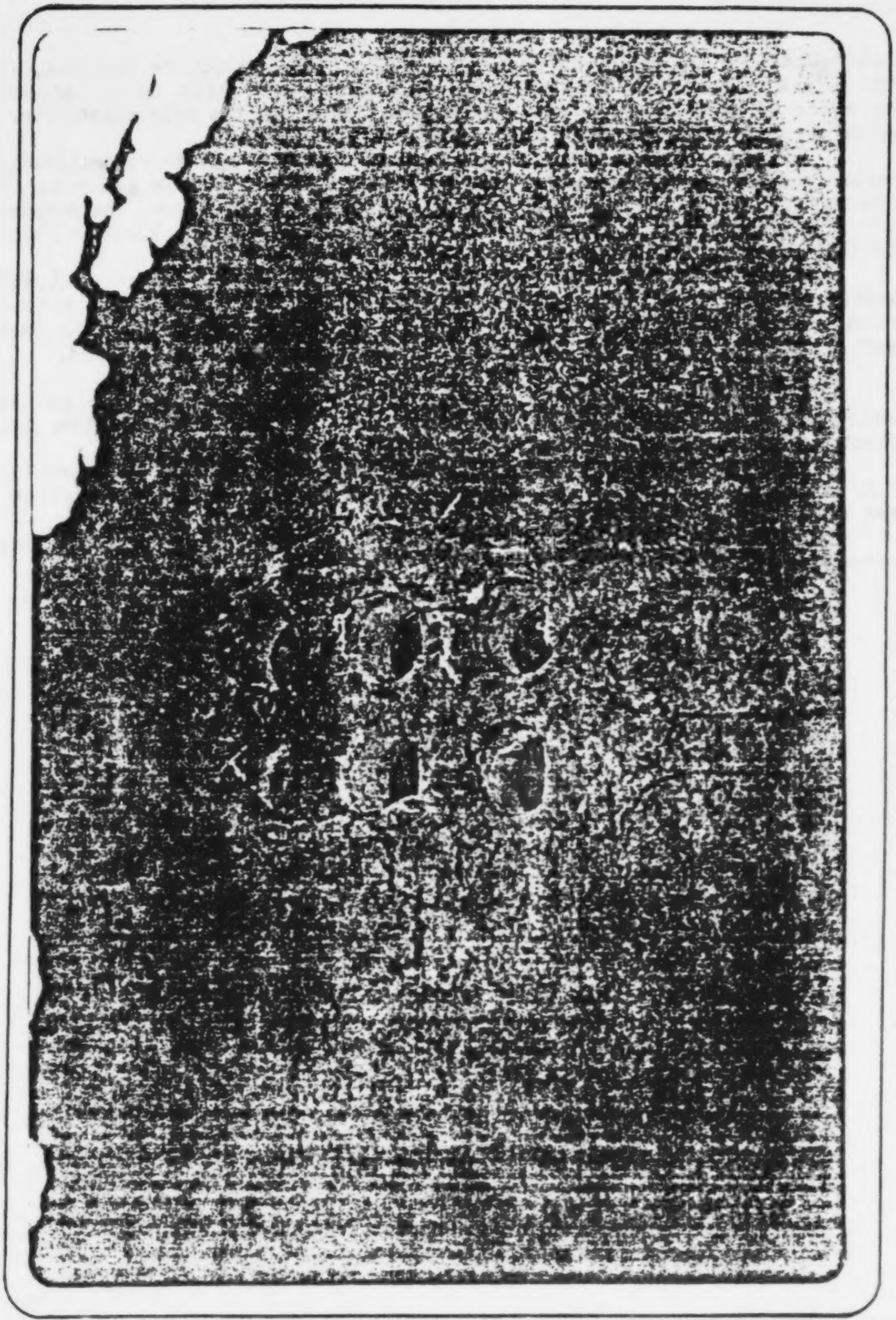

FIGURE T-13. SIX DILUTION SIDEWALL SECONDARY OVERFIRE AIR JETS AT COPENHAGEN:AMAGER

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recirculated flue gas air, poorer in O_2, should be used. In contrast, if the refuse is "cool" or wet, then ambient boiler room, rich in O_2, should be used. Of the European vendors visited, Volund is the only manufacturer which arranges extensively to use recirculated flue gas.

The recirculation flue gas fan has a damper that is automatically controlled. It sends a larger or smaller quantity of the flue gas back to the furnace depending on the furnace combustion temperature. The dampers are adjusted so that the furance temperature is always 900 to 1,000 C (1652 to 1832 F).

At Amager, where the refuse is cooler than at West at 1,800 kcal/kg (7536 kJ/kg) (3240 Btu/pound), they now use only ambient boiler room air. Refractory life has improved. The air is not put through the back wall where the flue gas recirculation air had been previously inserted.

West Units No. 1-3, unlike Unit No. 4, use hot flue gas as secondary air. The air is drawn from the flue gas leaving the hot electrostatic precipitator.

Table T-2 presents key design parameters for the four fans: (1) F.D. primary air, (2) F.D. secondary air, (3) I.D. flue gas recirculation, and (4) F.D. flue gas recirculation.

The Plant staff report that the four fans for each furnace have experienced only minor maintenance.

TABLE T-2. PRIMARY, SECONDARY, FLUE GAS AND RECIRCULATION FAN PARAMETERS AT COPENHAGEN:AMAGER

	Primary Air Forced Draft	Secondary Air Forced Draft	Flue Gas Induced Draft	Flue Gas* Recirculation
Fans per Furnace	1	1	1	1
Volume of Air (Nm^3/hour)	45,000	35,000	107,000	45,000
Static Pressure (mm Water)	230	460	170	220
Temperature (° C)	30	30	350	350
Fan Revolutions (rpm)	1,490	1,670	1,010	1,460
Belt Driving	yes	yes	yes	yes
Motor Power (Hp)	75	150	220	150

* Flue Gas Recirculation, originally installed, is no longer used.

BOILERS

The term "boiler" has varying meanings as described below. As a result this chapter has a unique organization with key headings as follows:

- What is a Boiler
- Summary of Boiler-Furnaces
- General Boiler Designs
- Comments about Specific Boilers
- Superheater Sections of Boilers, General Comments
- Comments about Specific Superheaters
- Steam-to-Refuse Ratio
- Boiler Cleaning
- Metal Wastage (Corrosion and Erosion) of Boiler Tubes
- References about Boilers

What is a Boiler?

In this research on refuse-fired steam-and hot water-generators the most important single component of the plant and often the most costly, is the boiler. However, as pointed out in 1966 by Fryling in "Combustion Engineering,..." the word "boiler" may not convey the same meaning to all engineers. The primary function of a boiler is to generate steam, and this naturally suggests the use of the terms "steam generator" and "steam generating unit" as equivalent to boiler. There have been some attempts to restrict the meaning of the word "boiler" to that portion of a steam generator in which water is transformed to the vapor phase, but these have only led to confusion without gaining widespread acceptance. In a similar sense, many have advocated the phrase "steam generator" or "steam generating unit" as a more universal designation than boiler, but usage of the latter persists in both lay and engineering circles. In fact, there is much evidence to support the view that the word "boiler" is gaining ascendancy. In simplest terms a boiler is a mechanical device to convert water to steam."

However, some of the plants visited produce hot-water for district heating systems. These are also said to use "boilers", although no actual boiling of water occurs in those pressure vessels.

Figure U-1 shows a typical plant, the one at Baden-Brugg, Switzerland. The figure shows an outer envelope designated "Refuse-fired Steam Generator" which encompasses the entire operating system from the refuse pit to the chimney. Inside that plant a smaller envelope encompasses the boiler. This smaller area is a complex system of components which varies considerably from plant to plant but which has one essential characteristic: all of the components are interconnected as a fluid system containing water or steam or a mixture of the two at essentially a constant pressure throughout.

There is yet a third envelope loosely called the "boiler". More properly, it would be called the "boiler convection section". It is the set of tube bundles that actually transforms the preheated water (from the wall tubes and the economizer) into steam. Usually the steam leaving the "boiler convection section" will enter the superheater.

The predominant boiler type in the most advanced European waste-to-energy systems is the water-tube-walled primary furnace plus a

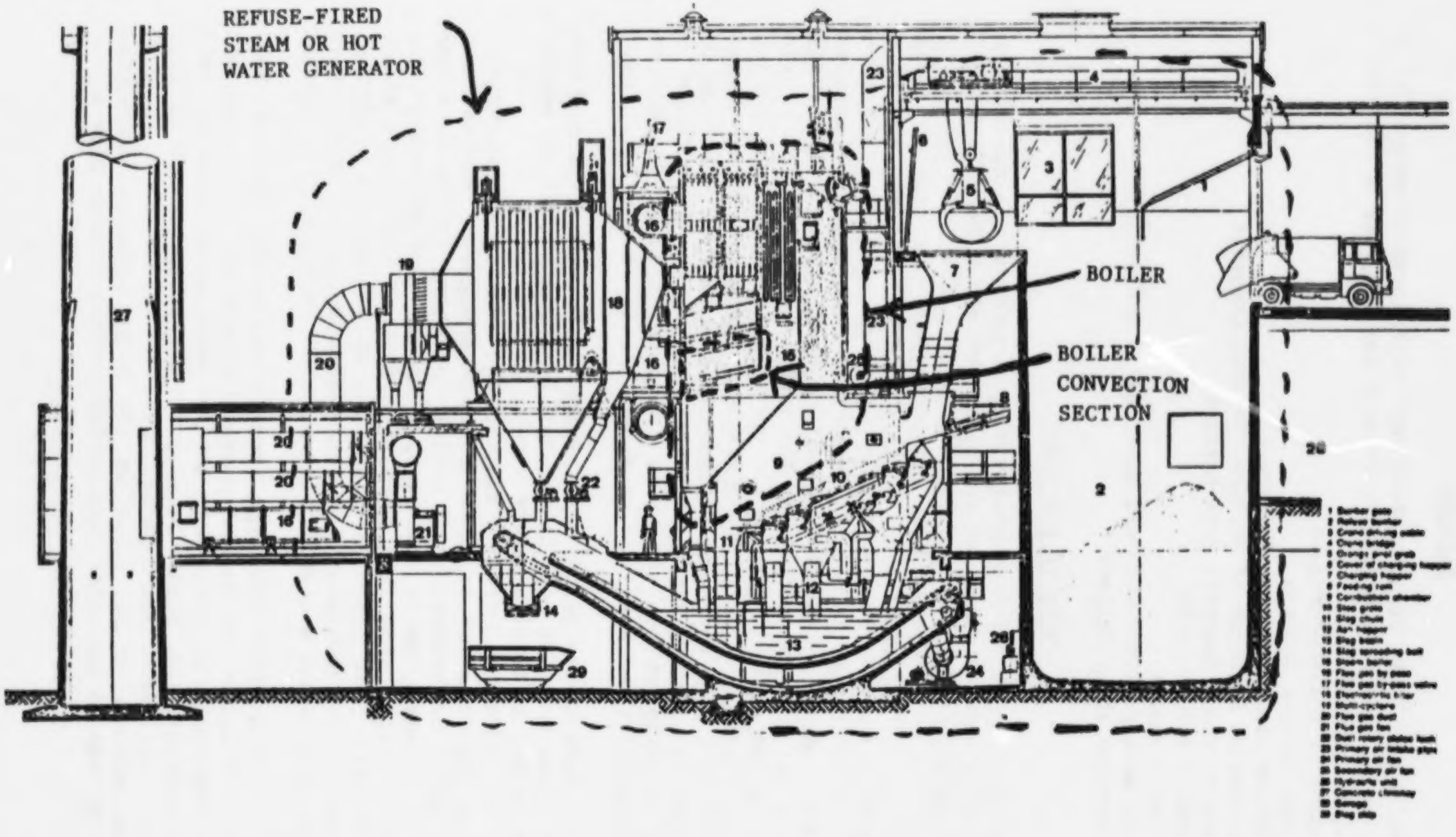

REFUSE-FIRED
STEAM OR HOT
WATER GENERATOR
BOILER
BOILER
CONVECTION
SECTION
1 Bunker gate
2 Refuse bunker
3 Crane driving cabin
4 Crane bridge
5 Orange peel grab
6 Cover of charging hopper
7 Charging hopper
8 Feeding ram
9 Combustion chamber
10 Slag grate
11 Slag chute
12 Air hopper
13 Slag basin
14 Slag spreading belt
15 Steam boiler
16 Flue gas by-pass
17 Flue gas by-pass valve
18 Electrostatic filter
19 Multi-cyclone
20 Flue gas duct
21 Flue gas fan
22 Dust rotary sluice belt
23 Primary air intake pipe
24 Primary air fan
25 Secondary air fan
26 Hydraulic unit
27 Concrete chimney
28 Garage
29 Slag skip

FIGURE U-1. GRAPHICAL DEFINITION OF OVERALL STEAM GENERATION PLANT AND THE SPECIFIC COMBINATION OF COMPONENTS CALLED THE BOILER.

similar tube-walled radiant pass followed by various arrangements of convection-tube sections. There are many variations of this arrangement plus a few significant plants which still depend upon refractory-walled primary furnaces, and a few small ones make very effective use of the ancient firetube boiler principle.

Because of the many variations among even the newest plants, it is evident that the evolution of waste-to-energy boiler-furnaces, which began to use the water-tube wall concept in the 1960's, is still in progress. This section of our report describes the background and current status of that evolution.

Definition of Boiler Terms

Before discussing details of the various boiler systems the following definitions are provided to assist the reader in understanding the terms used. These definitions have been taken from the book "Combustion Engineering" edited by Fryling.

Air Heater or Air Preheater - Heat transfer apparatus through which air is passed and heated by a medium of higher temperature, such as the products of combustion or steam.

Attemperator (Authors' definition) - A desuperheating device to inject very pure water into the steam between superheater bundles in order to control final superheated steam temperature.

Boiler - A closed pressure vessel in which a liquid, usually water, is vaporized by the application of heat.

Boiler (Authors' definition) - A closed pressure vessel, a set of interconnected tubes and drums acting as a fluid system containing water or steam or a mixture of the two at essentially a constant pressure throughout that has a function of producing superheated water, steam, or heated steam.

Water Tube - A boiler in which the tubes contain water and steam, the heat being applied to the outside surface. Also, see Steam Generating Unit.

Bent Tube - A water tube boiler consisting of two or more drums connected by tubes, practically all of which are bent near the ends to permit attachment to the drum shell on radial lines.

Fire Tube - A boiler with straight tubes, which are surrounded by water and steam and through which the products of combustion pass.

Boiler Convection Bank - A group of two or more rows of tubes forming part of a water tube boiler circulatory system and to which heat is transmitted mainly by convection from the products of combustion.

Boiler Slag Screen - A screen formed by one or more rows of widely spaced tubes constituting part of, or positioned in front of, a water tube boiler convection bank, and functioning to lower the temperature of the products of combustion and to serve as an ash cooling zone.

Desuperheater - Apparatus for reducing and controlling the temperature of a superheated vapor. (Also called an Attemperator).

Economizer - A heat recovery device designed to transfer heat from the products of combustion to a fluid, usually feedwater.

Furnace Slag Screen - A screen formed by one or more rows of tubes arranged across a furnace gas outlet, serving to create an ash cooling zone for the particles suspended in the products of combustion leaving the furnace.

Pendant Tube Superheater - An arrangement of heat absorbing elements which are substantially vertical and suspended from above.

Platen - A plane surface receiving heat from both sides and constructed with a width of one tube and a depth of two or more tubes, bare or with extended surfaces.

Screen Tubes - A group of large diameter water tubes usually located immediately before the superheater tubes to reduce flue gas temperature and hence superheater tube corrosion.

Steam Generating Unit - A unit to which water, fuel, and air are supplied and in which steam is generated. It consists of a boiler furnace, and fuel burning equipment, and may include as a component parts water walls, superheater, reheater, economizer, air heater, or any combination thereof. Also, see boiler.

Steaming Economizer - An economizer so designed that some of the fluid passing through it is evaporated.

Stud Tube Wall - A wall containing water tubes covered with refractory which is held in place by stud anchors attached to the tubes.

Superheater - A group of tubes which absorb heat from the products of combustion to raise the temperature of the vapor passing through the tubes above the temperature corresponding to its pressure.

(a) Convection superheater - A superheater so arranged and located to absorb heat from the products of combustion mainly by convection.
(b) Radiant superheater - A superheater so arranged and located to absorb heat mainly by radiation.

Summary of Boiler-Furnaces

European refuse has now reached high enough levels of heat value that in large power-generating units consuming 300 tons/day and up, the furnace is best cooled by water tubes. However, because of the corrosive action of chloride deposits on these tubes, they must be covered by plastic silicon carbide or alumina refractory held in place by welded studs. This refractory coating must extend upward to protect the lower third or half of the first or radiation pass.

Most superheaters suspended at the top of the first pass are subject to rapid chloride corrosion because of overheating of the chlorides in the ash deposits, especially when long flames reach up to them during unavoidable "excursions" characteristic of mass burning. A long water-cooled first pass, followed by a similar long open second pass, appear to be very important in keeping the ash deposits on the superheaters cool enough that chloride attack is minimized.

Ample secondary air up to 25 percent of the total combustion air, delivered at high velocities from multiple small jets, is essential to completing combustion in the furnace and avoiding long flames which may cause corrosion.

Excessive use of high-pressure steam-driven soot blowers is a common source of tube erosion-corrosion. Use of a horizontal-flow type superheater and boiler sections directly following the first or radiation pass enables less drastic cleaning by gentle rapping of the vertically hung tubes. But this is no insurance against chloride corrosion if the furnace gases have insufficient flow path and time to cool before they strike the superheater.

Costs for tube-corrosion-caused maintenance are unclear. They were almost zero at Zurich and minimal at Werdenberg, Wuppertal, Krefeld, Uppsala, Horsens, Copenhagen, and Dieppe-Deauville. They were highest at Duesseldorf, Issy, The Hague, and Gothenburg. Through changes in operation tube materials and shielding these plants have reduced the effects of corrosion. None has abandoned the mass-burning approach and plans for expansion or building additional plants continue at some locations.

Overall Boiler Design

It has taken a long time for some waste-to-energy plant designers to become fully aware that refuse is not coal. Refuse is

- More variable
- Less dense, but subject to extreme variation in density, especially if very wet
- High in chlorine

- Always changing
- Usually has much higher alkali content in the ash
- Feeds poorly
- Can lose ignition if wet or can almost explode with threating intensity.

Boilers and stokers, following well established design, have not always been designed to cope with these properties. Accordingly, refractories, tube walls, and superheaters have suffered.

Some designers still do not seem to be aware of these effects.

On the other hand, in about 1965 or 1967, someone in Martin and Von Roll evidently began to perceive that the superheater must not be located where, even momentarily, its ash deposits could become overheated. Thus, the Paris (Issy) (1965) and Ludwigshafen (1967) designs had the superheater after a second, open radiant, water-tube pass.

But Martin didn't use this again until 1971 at Kezo-Hinwil and 1972 at Hagenholz. And VKW even hung the superheater in the first pass as recently as 1972 in Unit 5 at Duesseldorf. Then in 1976 at Krefeld and Wuppertal, VKW placed the superheater beyond the first pass. Now in 1976, Widmer & Ernst at Werdenberg has included the open second pass ahead of the superheater.

Oddly, when Von Roll built Saugus near Boston in 1975, they included no open second pass; but at Stapelfeld, to be completed in 1980, Widmer & Ernst will. So the choice between the lower cost, close-coupled boiler-superheater arrangement, and the more costly double-open pass is still not clear among the various designers.

General Boiler Designs

The following sections summarize the significant details of the various boiler configurations investigated. As has already been discussed in earlier sections there are good reasons for the differences in plant design that were encountered and there is much evidence of a continuing process of evolution. At this time, 1977-78, it appears that the current "best" boiler-furnace design in use for large, high-pressure units is the completely water-tube-walled furnace and radiant section, studded and coated with thin refractory in the intense burning zone, followed by one or more long, open, vertical radiation passes preceding a convection-type superheater and boiler-convection passes and an economizer.

However, an emerging newer philosophy is to follow the tall water-tube-walled chambers by a long horizontal superheater and convection section. This is called the "dacha" boiler because of its extended horizontal configuration. Figure U-2 shows such a design for the proposed Staplefeld plant at Hamburg. The purpose of this design is primarily to enable all of the boiler convection tubes and, in many cases, the superheater tubes as well, to be suspended vertically in the horizontal gas passage. This arrangement makes it relatively easy to remove and replace failed tubes from the top. It also facilitates the removal of ash deposits from those vertical tubes by means of mechanical rapping. Thus, the common threat of the erosive action of steam-jet soot blowers is eliminated. It is too early to tell how effective this cleaning method will be in the long run.

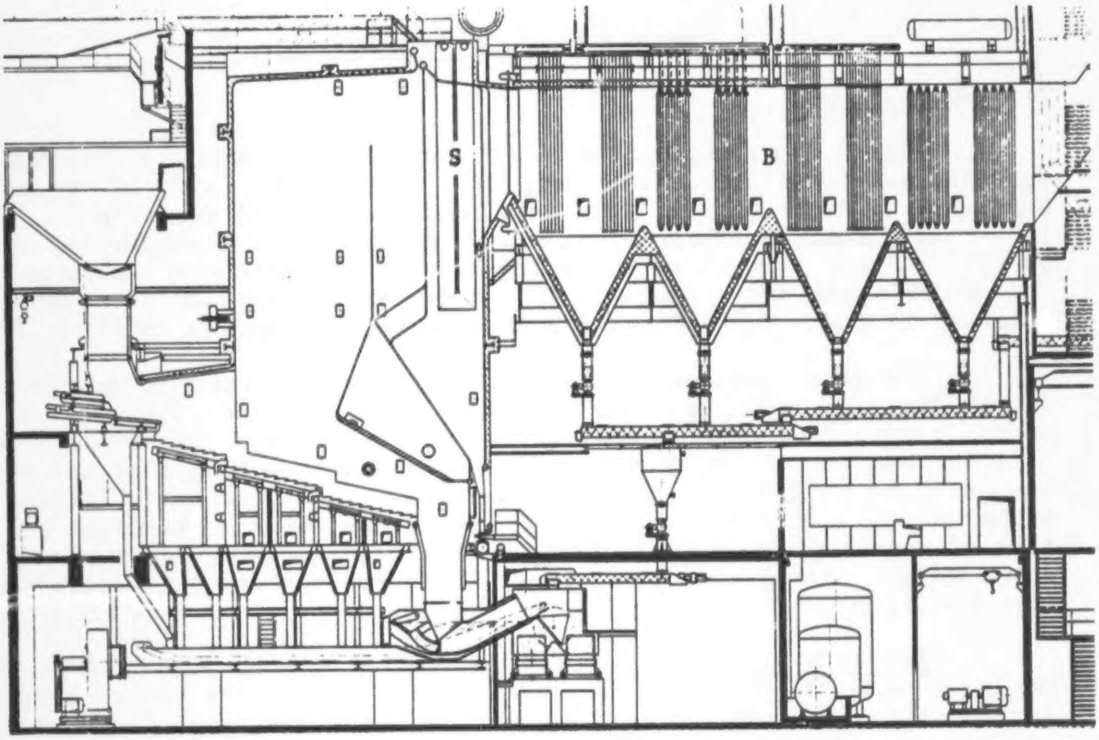


FIGURE U-2. DACHA TYPE SUPERHEATER AND BOILER CONVECTION ARRANGEMENT FOR PROPOSED STAPELFELD PLANT AT HAMBURG (COURTESY WIDMER & ERNST). S - Superheater
B - Boiler Convection Section

It is notable that in Figure U-2 of the proposed Stapelfeld plant (to begin operation about 1979) the platen-type superheater is preceded by an open, water-tube-walled second pass to assure that the superheater is not touched by excessively hot flame or furnace gases. Furthermore, it is in a location such that it is completely shielded from furnace radiation. A similar design philosophy is apparent at the Werdenberg and Zurich plants to be discussed later under superheaters. Both of these factors will combine to keep the ash deposits on the superheater from becoming heated to the point that chlorine may attack the metal. This is discussed at length under "Metal Wastage".

Comments About Specific Boilers

Werdenberg Boiler

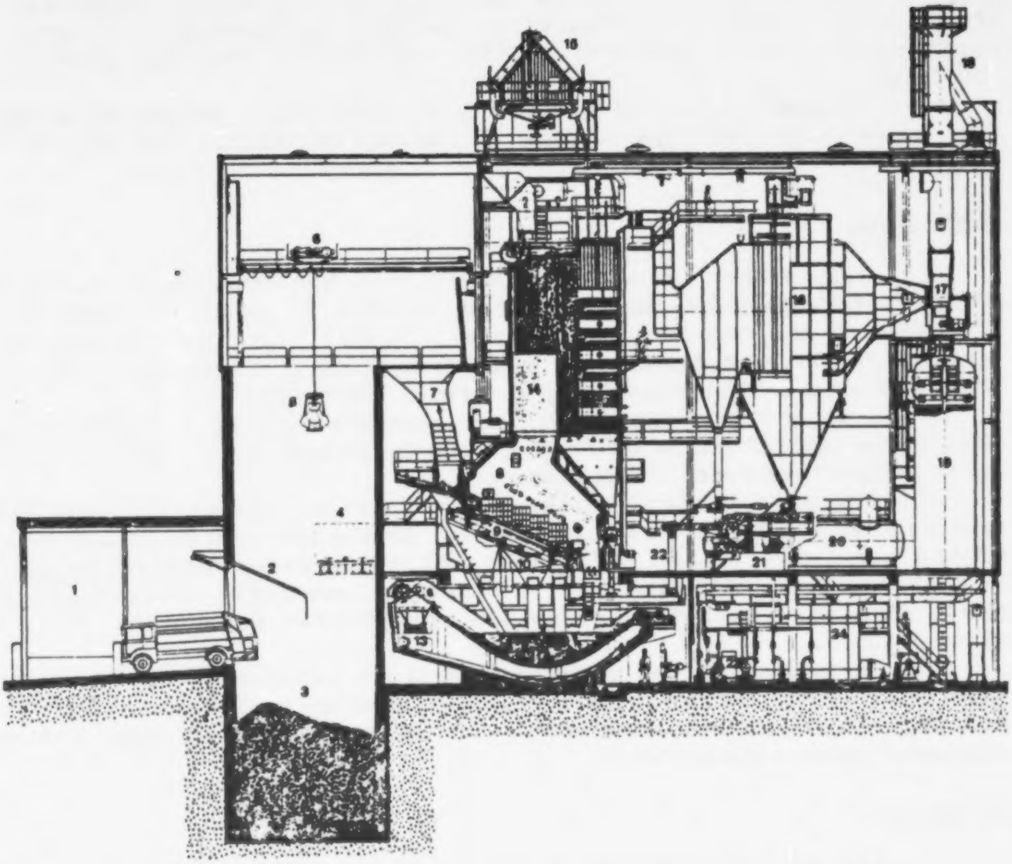
Figure U-3 shows a cross section of the single boiler in the small Werdenberg-Leichtenstein plant started up in April, 1974 at Buchs, Switzerland. Although this is a very small boiler: 12 tonne/hr (26,460 lb/hr) rated steaming capacity with a peak capacity of 16 tonne/hr (35,275 lb/hr), in many ways it embodies the current culmination of evolution of the vertical-pass, water-tube wall type of boiler discussed earlier. Boiler pressure is 39 bar (3930 KPa) 570 psia. Superheat temperature is 395 C (740 F).

The first pass above the furnace, the radiant pass, is water-tube walled. The wall tubes are nearly tangent to each other. The tubes are carbon steel, 76.1 mm (3.0 in) dia., 4 mm (0.16 in) thick, spaced on 78 mm (3.1 in) centers. Although the tubes are nearly touching they are not connected by welded fins to form a membrane wall. Apparently European boiler designers have been reluctant to use the welded fin, membrane wall type of construction because of differential expansion problems that might cause fatigue cracks to form. However, it is now beginning to appear in most new designs.

Second Boiler Pass. When the upward-flowing gases reach the top of the first pass, they then are turned horizontally into the entrance of a second water-tube walled vertical pass in which the gases are further cooled as they flow downward. These water tubes have no studs nor coating as by this time the gases are cooled so that corrosion and erosion are no longer a threat to water tubes.

Boiler Operation. Reliability of this relatively new plant (1974) was stated to be 100 percent except for scheduled shutdowns. Few repairs have yet been required (1977) and at least a 20-year life is expected. An amortization period of 20 years is common in Switzerland.

In 1975, the new plant was operated at an excessive rate for only 3 or 4 days per week. The remainder of the time, steam was supplied by the oil-fired standby boiler. Design heat input is 14 x 10^6 kcal/hr (55 x 10^6 Btu/hr) (58.5 x 10^6 kJ/hr). However, the actual input ranged up to 17-18 x 10^6 kcal/hr (71.4 x 10^6 Btu/hr) (75.3 x 10^6 kJ/hr) amounting to a 20 to 29 percent overload. Formal warning to the owner by the manufacturer of the possiible deleterious consequences of such overloading led to subsequent operation at more nearly normal loading. At the time of our visit, May 2-4,



1 Delivery Area
2 Bunker Door
3 Refuse Bunker
4 Crane Pulpit
5 Crane
6 Refuse Grab Bucket
7 Charging Hopper
8 Incinerator Furnace
9 Step Grate

10 Ash Hopper
11 Residue Chute
12 Residue Basin
13 Residue Conveyor Belt
14 Steam Boiler
15 Air Cooled Condenser
16 Electrostatic Precipitator
17 Exhaust Gas Fan

18 Steel Chimney
19 Hot Water Heater
20 Feed Water Tank
21 Turbogenerator
22 Collected Flyash Conveyor
23 Feedwater and Heating Water Pumps
24 Oil-Fired Stand-by Boiler

FIGURE U-3. SECTION THROUGH WERDENBERG-LIECHTENSTEIN WASTE-TO-ENERGY PLANT, COURTESY WIDMER + ERNST (ALBERTI-FONSAR)

1977, there appeared to have been no permanent damage resulting from the period of overloading.

On April 1, 1977, the Swiss organization of Pressure Vessel Inspectors issued a report on the inspection of this boiler. They reported the boiler in good condition with some dirty surfaces but no unusual tube wastage. Some steel supports in the superheater section showed some corrosion.

In summing up the experience at this small, new plant, it appears that conservative, multipass boiler design and relatively low firing rates have nearly eliminated tube corrosion as a significant problem.

Baden-Brugg

Figure U-4 is a cross section of the two-boiler Baden-Brugg 200-tonne-per-day plant that started up in 1970. It is of interest because it preceded the one-boiler Werdenberg (1974) plant by 4 years and was designed by the same experienced designers. Steam pressure is 40 bar (4000 kPa) (590 psia), superheater temperature is 400 C (752 F).

A major difference from the later Werdenberg design is that in this older design at Baden-Brugg, there is no open second pass to cool the gases before they reach the superheater.

The main furnace is largely refractory walled. Only the sloping rear wall of the furnace is water-cooled. As the combustion gases rise out of the partially cooled refractory walled furnace, they are accelerated into the first or radiation pass, a tall open, vertical, water-tube walled pass. From this pass they enter the superheater consisting of vertical sinuous tubes.

To summarize the Baden-Brugg plant experience, some wall tubes have failed. This corrosion failure was stopped by applying wall refractory coating. There has been superheater corrosion which is now under control as discussed under superheaters.

Duesseldorf

Figure U-5 shows one of the four large boilers first started up at Duesseldorf in November, 1965. Their design was based primarily on 4 years (1961-1965) of developmental work using a new roller-type grate for refuse applied to an old coal-fired refractory furnace in the municipal power plant there. Referring back to Figure S-1 showing the trend of heating values of European refuse, it can be understood that in that early period (1961-1965) the furnaces and boilers were designed for very low heat value in the refuse. Accordingly, in these first four boilers there is little water cooling of the furnace and no open second pass. As will be discussed under "Superheaters", the suspended platen-type superheaters are located in a potentially "hot" position at the top of the first, radiant pass. The rather startling rise in heat value of Duesseldorf refuse, 70 percent increase from 1961 to 1975, has caused corrosion problems for this very "compact" boiler design.

The pilot unit burning 200 tonnes per day, was operated intermittently for a total of 22,000 hours from 1961 to 1965 and provided the design basis for a small plant (110 tonnes per day) at Rosenheim

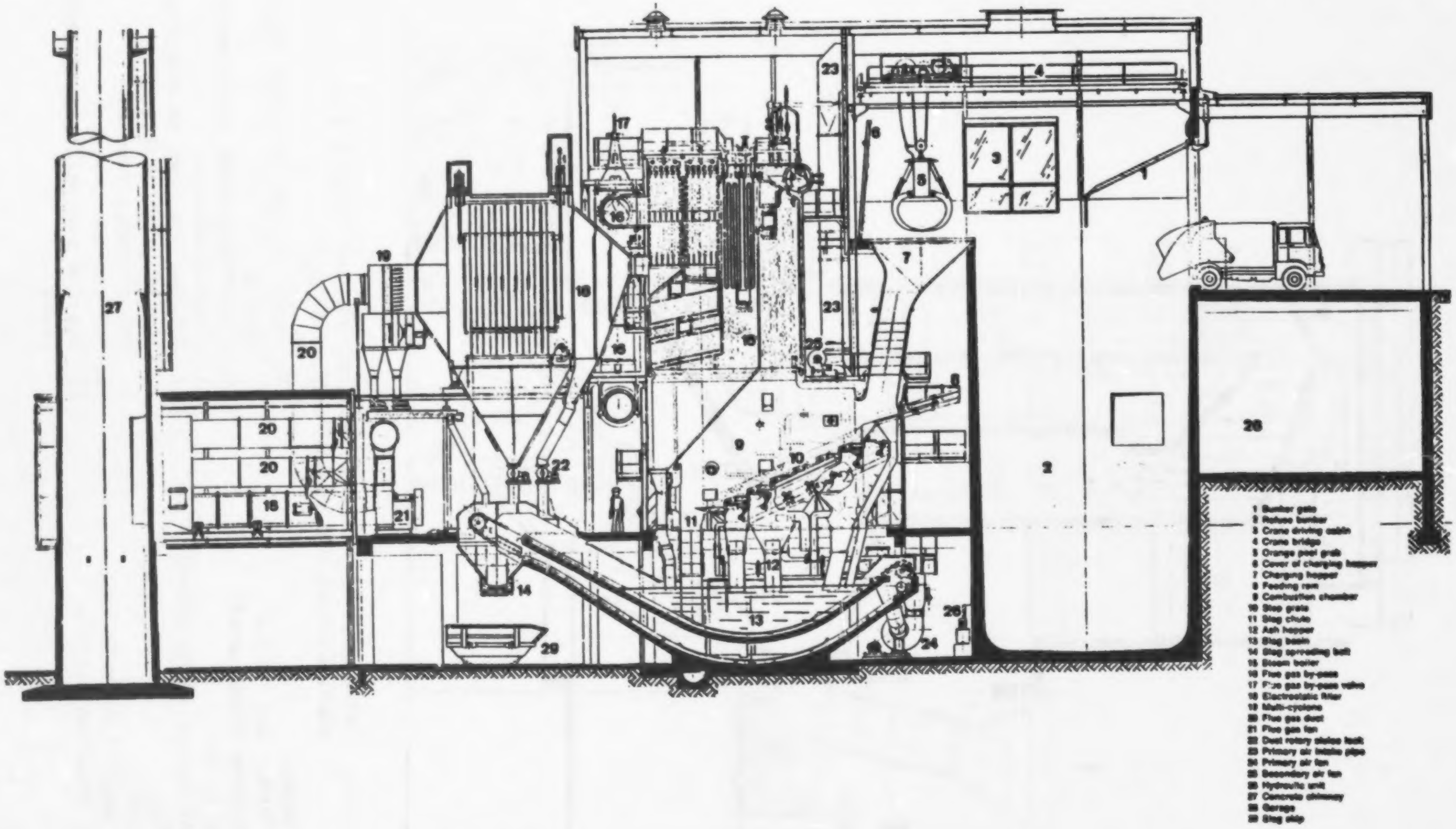

1 Bunker gate
2 Refuse bunker
3 Crane driving cabin
4 Crane bridge
5 Orange peel grab
6 Cover of charging hopper
7 Charging hopper
8 Feeding ram
9 Combustion chamber
10 Step grate
11 Slag chute
12 Ash hopper
13 Slag basin
14 Slag spreading belt
15 Steam boiler
16 Flue gas by-pass
17 Flue gas by-pass valve
18 Electrostatic filter
19 Multi-cyclone
20 Flue gas duct
21 Flue gas fan
22 Dust rotary sluice lock
23 Primary air intake pipe
24 Primary air fan
25 Secondary air fan
26 Hydraulic unit
27 Concrete chimney
28 Garage
29 Slag skip

FIGURE U-4. CROSS SECTION OF BADEN-BRUGG PLANT

(Courtesy Widmer + Ernst)

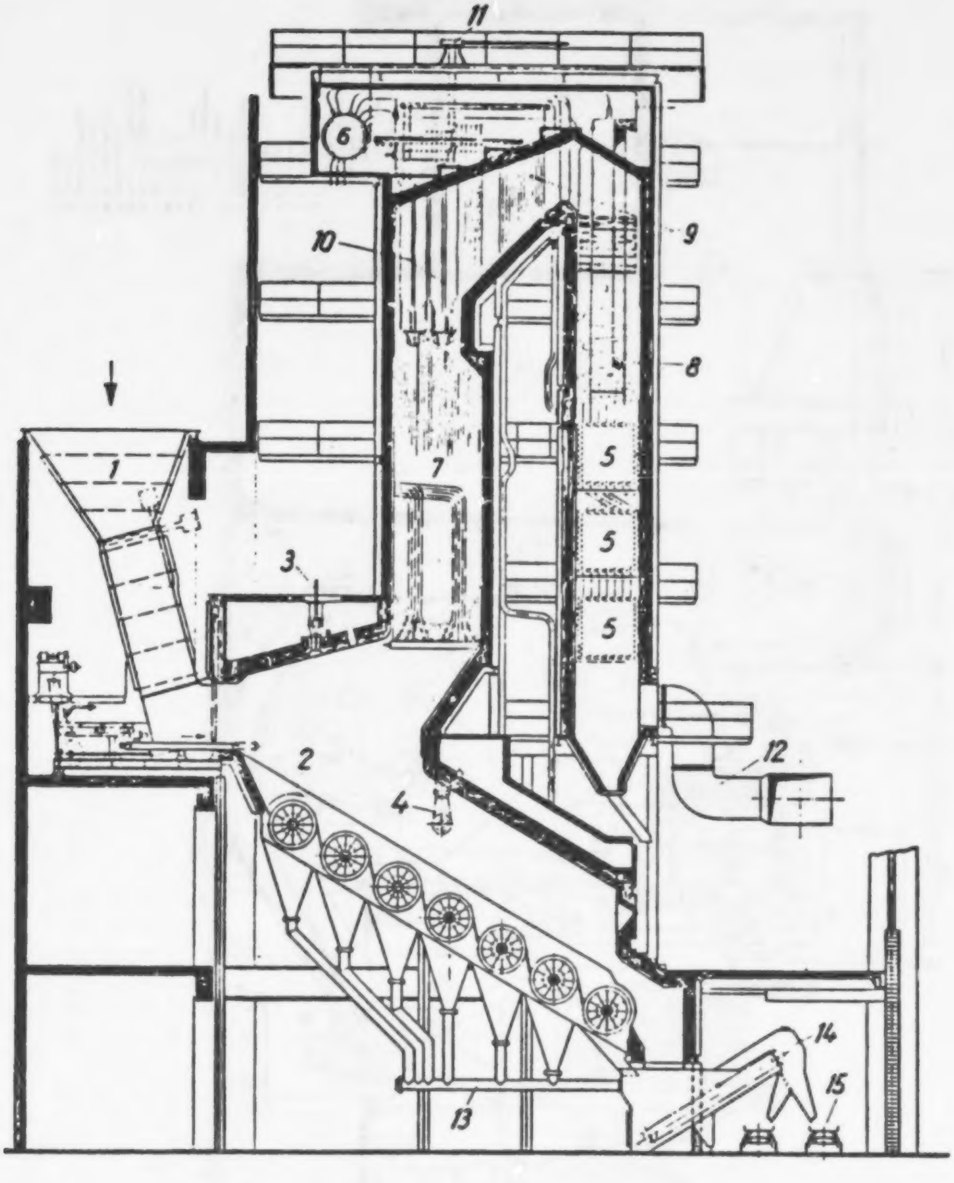


FIGURE U-5. CROSS SECTION OF ONE OF BOILERS NO. 1-4 (COURTESY OF STADTREINUNGS UND FUHRAMT DUESSELDORF)

1. Refuse hopper
2. Refuse feeder and roller grate "system Duesseldorf"
3. Ignition burner
4. Heavy oil burner (both sides)
5. Economizer
6. Steam drum
7. Radiant water-tube-wall boiler
8. Boiler convection section
9. First and second stage superheater
10. High-temperature superheater
11. Steam discharge
12. Exhaust gas duct to electrostatic precipitator
13. Ash siftings removal
14. Wet residue conveyor
15. Residue removal to processing plant

(1964), and for the first four full size units at Duesseldorf--the first of which was started in November, 1965.

For the reasons cited earlier, when the design transition was made in 1964-1965 from the old refractory-walled pilot furnace to the new, full-scale units, No. 1 through 4, there was an understandable reluctance to use a fully water-tube walled furnace. Although the lower heating value of Duesseldorf refuse shown in Figure S-1 had risen to 1,220 kcal/kg (5,108 kJ/kg (2,196 Btu/lb) by 1963, that was still a relatively low level. Hence, the need for some refractory in the main furnace to reflect heat to the raw refuse so as to facilitate rapid ignition and burning. Final steam temperature is 500 C (932 F).

The sloping roof of Furnaces No. 1 through 4 is in two parts as seen in Figure U-5. The front roof is cooled by water tubes, as well as the longer rear roof.

First Open Boiler Pass, Units No. 1-4. Burning is usually not complete as the gases flow upward out of the main furnace. This means that the ash particles carried in the burning gases are usually hot enough, over 982 C (1800 F), to be sticky. Accordingly, enough volume must be provided to allow time and radiation to the gases so that deposits of ash particles will be dry and will be below the corrosive range. The problems with wall-tubes in these first four furnaces have been described under "Furnace Wall".

Furnace in Unit No. 5. The furnace for Unit No. 5, built in 1972, was altered in accordance with the experience gained in about 6 years' operation of Units 1-4. Also, the gas flow pattern in No. 5 was radically altered because of the rising heat value of Duesseldorf refuse. Instead of having the burning gases flow upward at an angle toward the furnace outlet as in Units 1-4, a sloping steam-generating water-cooled baffle was built in No. 5 above the fuel bed as shown in Figure U-6 in such a way that the gases first flow nearly parallel to the fuel bed. At the end of the baffle, they turn and flow upward toward the furnace outlet. This provides a longer flame path and residence time for the hot gases resulting from the higher heat value of refuse.

One desirable achievement of this new design is that by the time the gases reach the top of the furnace and enter into the first pass, they are well mixed and cool enough to reduce corrosion.

However, because of slagging of the uncooled furnace sidewalls, after 6,000 operating hours, the SiC lining of the front part of the furnace needed replacement. This problem has been disucssed under "Furnace Wall".

While the walls in Units 1-4 were either refractory or spaced water tubes shielded by high-temperature insulation, the nonrefractory water-tube walls in Unit No. 5 are "membrane walls"; that is, each tube has two welded fins, 10 to 12 mm (0.4 to 0.5 in) facing the adjacent tubes. The joint between the fins is also welded forming a solid, water-cooled membrane wall.

Boiler (Convection Section). The convection section of the boiler is located in the lower portion of the second pass as seen in Figure U-6. Some erosion by fly ash has been experienced in this area. In Boilers NO.

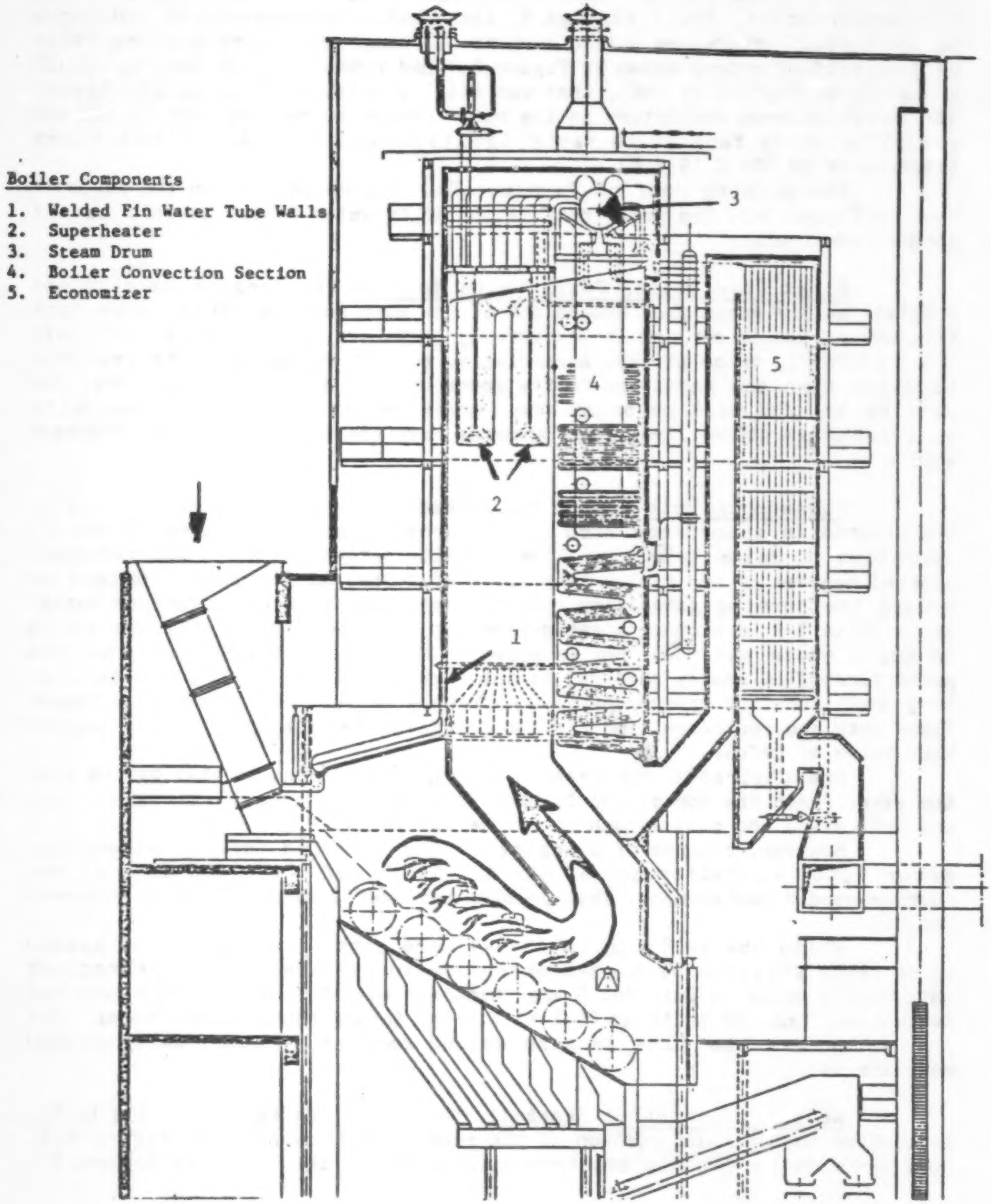

Boiler Components
1. Welded Fin Water Tube Walls
2. Superheater
3. Steam Drum
4. Boiler Convection Section
5. Economizer
3
4
5
2
1

FIGURE U-6. CROSS SECTION OF BOILER NO. 5 WITH ROLLER GRATE "SYSTEM DUESSELDORF" (COURTESY STADTWERKE DUESSELDORF KRAFTWERKE)

1-4, this occurred only at the outside of the first row of tubes where the gas flow pattern caused a concentrated stream of fly ash to impinge against the metal. In Boiler No. 5, after 28,000 hours, steel cladding was added to shield these tubes against erosion.

The Duesseldorf plant has controlled wall tube corrosion by means of rammed refractory coating on studded tubes. Because of the exposed position of the superheater in the first pass, corrosion is still a problem and tube shields, alloys, and coatings are still being tried.

Wuppertal and Krefeld

The six boilers at the relatively new plants of Wuppertal (1976) and Krefeld (1976), Germany, both near Duesseldorf, are very similar and show the influence of the experience gained by VKW at Duesseldorf. They are not primarily power generating units; hence, steam temperature is moderate--Wuppertal 350 C (662 F). Furthermore, neither of these newer plants has a platen-type superheater suspended from the top of the first pass. The boilers have membrane walls.

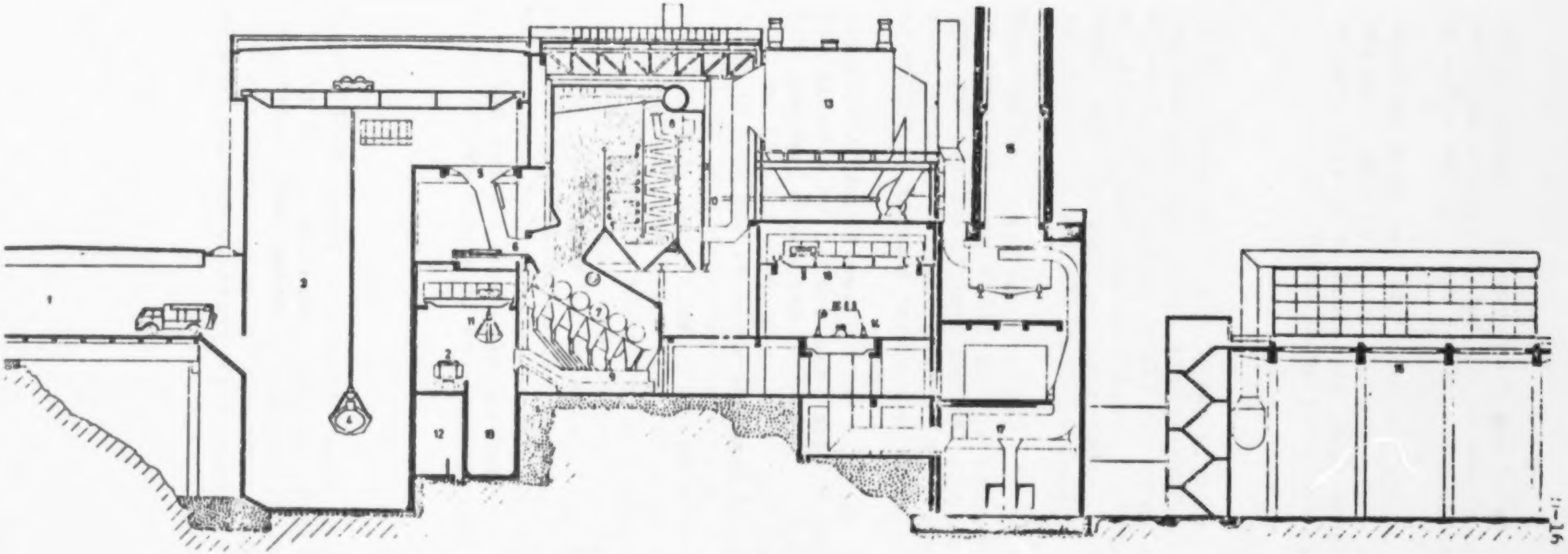
Figure U-7 shows the Wuppertal plant in which the 4 boilers each consists of a completely open water-tube walled first pass followed by second and third convection-type passes. The two Krefeld boilers are very similar except that mill-dried sewage sludge is fired into the first pass and most of the energy released in the plant by the burning of refuse is used in drying this sludge.

As at Duesseldorf, the 57 mm (2.3 in.) water-tubes forming the walls of the first radiataion pass are studded and coated to a height of about 2 to 3 meters (6.5 to 9.8 ft) at Wuppertal and about 3 meters (9.8 ft) at Krefeld. The welded studs are 10 mm in diameter (0.4 in), 20 mm (0.8 in) long, and are applied to the welded membrane walls at the rate of about 2,100/m^2 (195/ft^2). At Krefeld, the studs are covered with a 50 mm (2 in) thick layer of 90 percent silicon carbide. At Wuppertal, part of the coating is 50 percent SiC and another part 80 percent SiC as a comparative trial to ascertain which works best under the conditions at the plant.

Both the Wuppertal and Krefeld plants are too new (1976) to provide information on boiler reliability. Also at Wuppertal, only two boilers are operated at a time while the flue gas scrubbers for acid gas removal are being tessted. The Krefeld plant is also at part load and has not yet been finally tested. Hence, considerable time must elapse before a sufficient operational period has been accumulated to enable evaluation of these boiler designs.

Paris-Issy

Figure U-8 shows one of the four boilers at Issy (1965) which incorporated the results of much Parisian and other experience with boilers for waste fuel. The large, open first and second passes seem to represent the latest design to avoid high temperature corrosion problems; yet wall and superheater corrosion have occurred. This probably results from two factors:



(Courtesy Mullverbrennungsanlage Wuppertal GMBH)

1. Tipping floor
2. Ash removal clock
3. Refuse bunker
4. Refuse crane bucket
5. Refuse feed hopper
6. Refuse feed throat
7. Roller grate, "Duesseldorf Type"
8. Steam generator
9. Residue conveyor
10. Residue bunker
11. Residue crane and bucket
12. Storage
13. Electrostatic precipitator
14. Turbogenerator
15. Chimney
16. Air-cooled condenser
17. Flue gas washer
18. Generator-room crane

FIGURE U-7. **CROSS-SECTION OF WUPPERTAL PLANT**

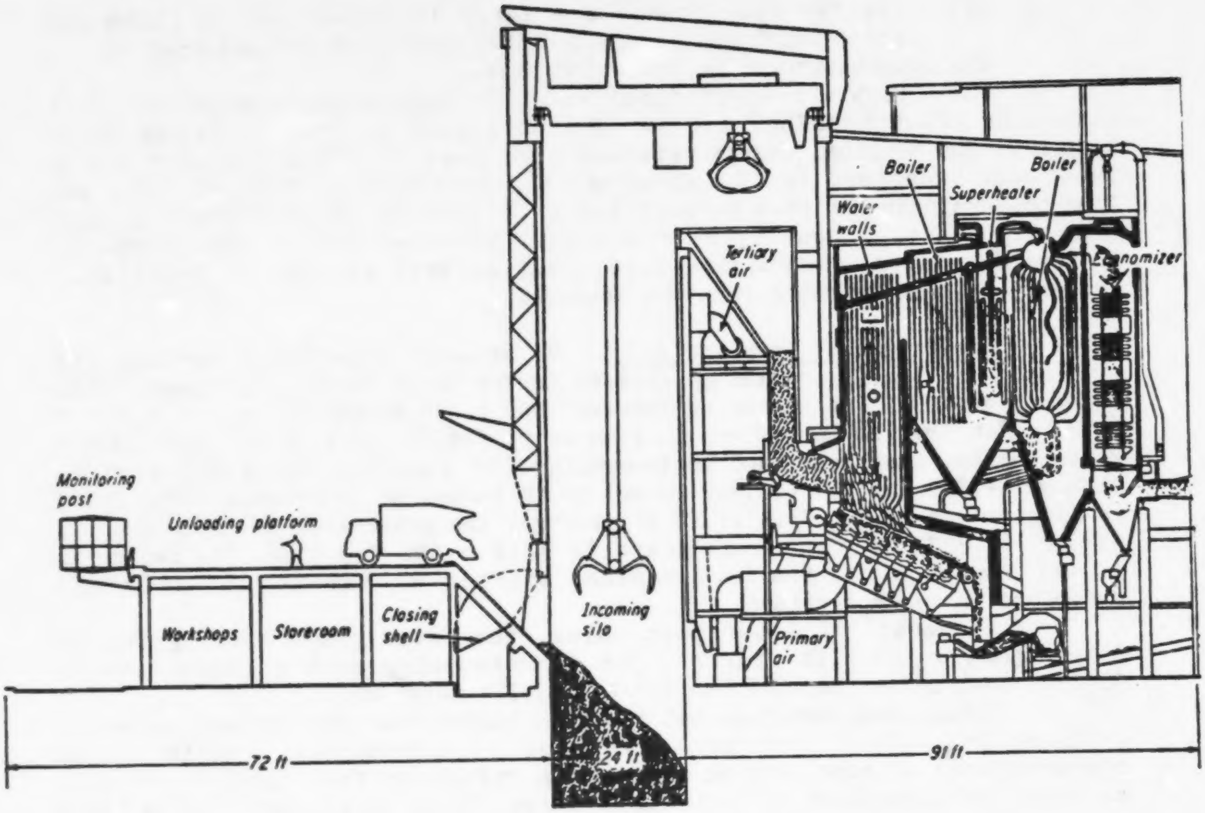

Boiler
Boiler
Superheater
Water walls
Economizer
Tertiary air
Monitoring post
Unloading platform
Workshops
Storeroom
Closing shell
Incoming silo
Primary air
72 ft
24 ft
91 ft

FIGURE U-8. ISSY-LES-MOULINEAUX INCINERATOR PLANT NEAR PARIS, FRANCE.

(1) These boilers are overloaded by as much as one third above the initial design rate.

(2) The two open passes are large in volume and in width and short which apparently provides less time for gas cooling.

The superheater is in the third pass.

In 1975, the average input rate per operating furnace was 19.1 tonnes/hr (21.0 tons/hr) and in 1976 this rose to 19.9 tonnes/hr (21.9 tons/hr). The original design rate was 15 tonnes/hr (16.5 tons/hr) which later was increased to 17 tonnes/hr (18.7 tons/hr). In 1975 and 1976, the four boilers operated 86.4 percent and 84.8 percent of the total elapsed time. This high intensity of operation is needed but it contributes to increased maintenance requirements, particularly because of inevitably higher peak burning rates than the average.

Comparison of Ivry and Issy. Of special interest regarding the evolution of waste-to-energy systems is the newer Paris-Ivry (June, 1969) plant (Figure U-9), also run by TIRU-EDF and built by Martin about 4 years later than Issy (started up in February, 1965). It has two much larger Martin units, each rated at 40 tonnes/hr (44 tons/hr) for 2,500 kcal/kg refuse (4,500 Btu/lb) (10,467 kJ/kg) or 50 tonnes/hr (55 tons/hr) for 2,000 kcal/kg refuse (3,600 Btu/lb) (8,374 kJ/kg). The grate area of each unit is 128 m^2 (1,377 ft^2) and each grate is 12.8 m (42 ft) wide. The design is almost identical to the Martin plant started at Hamburg in 1972 and described in later sections.

Thus, at the lower heat value, the rated grate burning rate is 390.6 kg/m^2/hr (79.9 lb/ft^2/hr). The corresponding heat release rate is 781,509 kcal/m^2/hr (287,582 Btu/ft^2/hr) (3,371 mJ/m^2/hr).

These rates are high but not much higher than the actual rates in 1976 at Issy when each unit averaged 19.9 tonnes/hr. Again, it is characteristic of mass burning units using refuse as fuel that there will be repeated excursions to much higher rates. It is very likely during these short periods that the chloride-containing deposits on the water-tube walls and superheaters can become overheated. If they do, the evidence is strong that chloride corrosion will occur. Thus, it is not surprising that during a brief visit to Ivry in 1975, before this project began, it was learned that the ninth different superheater cladding was then being tried in an eventually successful effort to achieve more than a 1-year life for the most exposed superheater tubes.

The superheater at Ivry differs from that at Issy in that the platens are all pendant in the "dacha" style. Gas flow is horizontal. There is no second radiant pass ahead of the superheater.

Steam temperature at Irvy is 470 C (878 F) while at Issy it is 410 C (770 F). At Irvy, steam pressure is 75 bars (1,088 psia) (7,501 kPa) and at Issy, 50 bars (725 psia) (5,001 kPa). Although the closer coupling of superheater-to-furnace at Irvy and its higher steam temperature would both indicate a higher corrosion potential than at Issy, the corrosion experience at both plants appears to be of about the same magnitude.

Hamburg-Stellinger-Moor

Figure U-10 shows one of the two Martin furnaces started up at Stellinger-Moor in 1970. The City of Hamburg had already had long

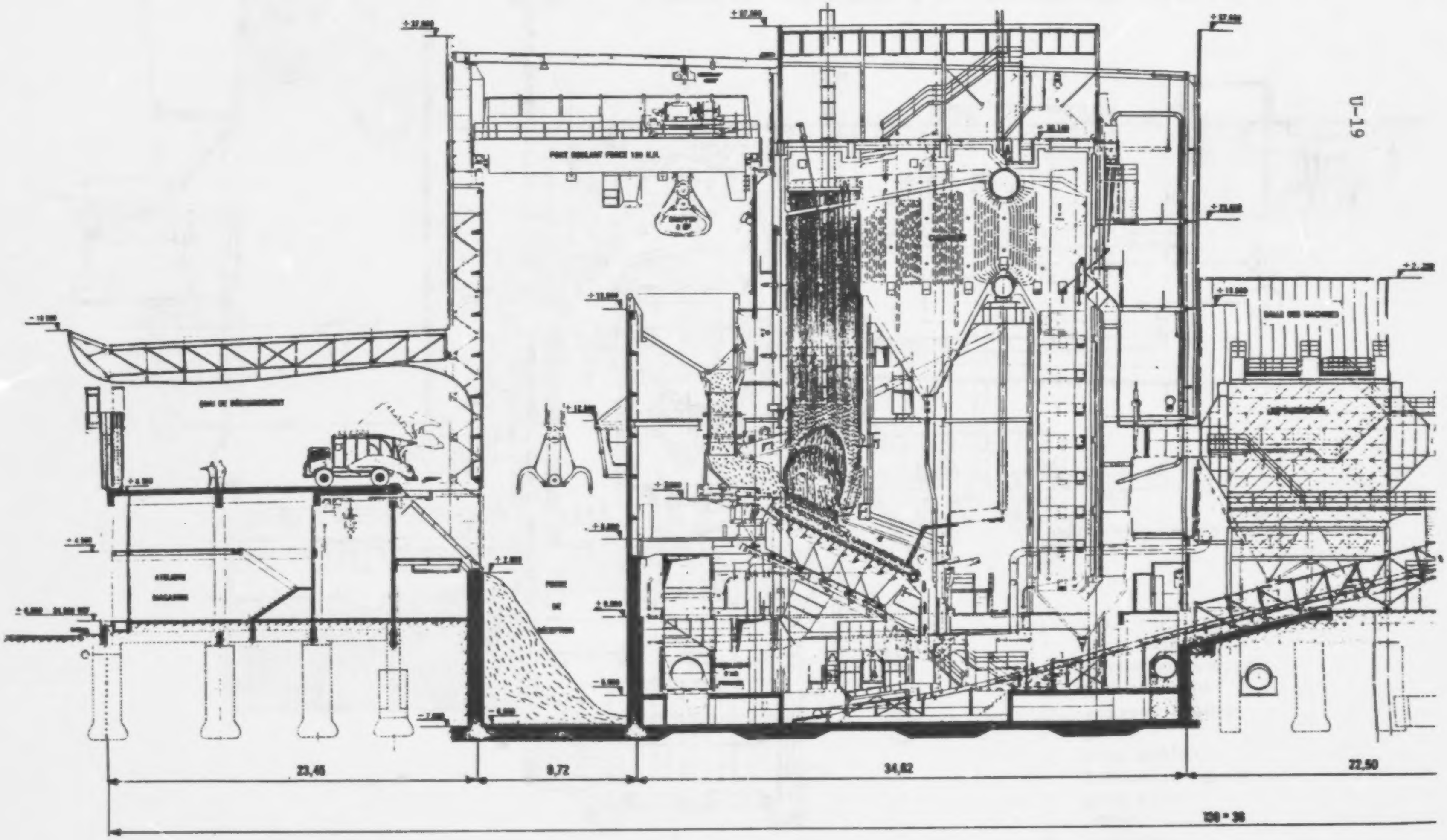

PONT ROULANT FORCE 120 K.N.
QUAI DE DÉCHARGEMENT
ATELIERS MAGASINS
FOSSE DE RÉCEPTION
SALLE DES MACHINES
23,45
9,72
34,62
22,50

FIGURE U-9. LARGE BOILERS AT IVRY BUILT FOR TIRU 4 YEARS AFTER ISSY (Courtesy Josef Martin Gmbh.).

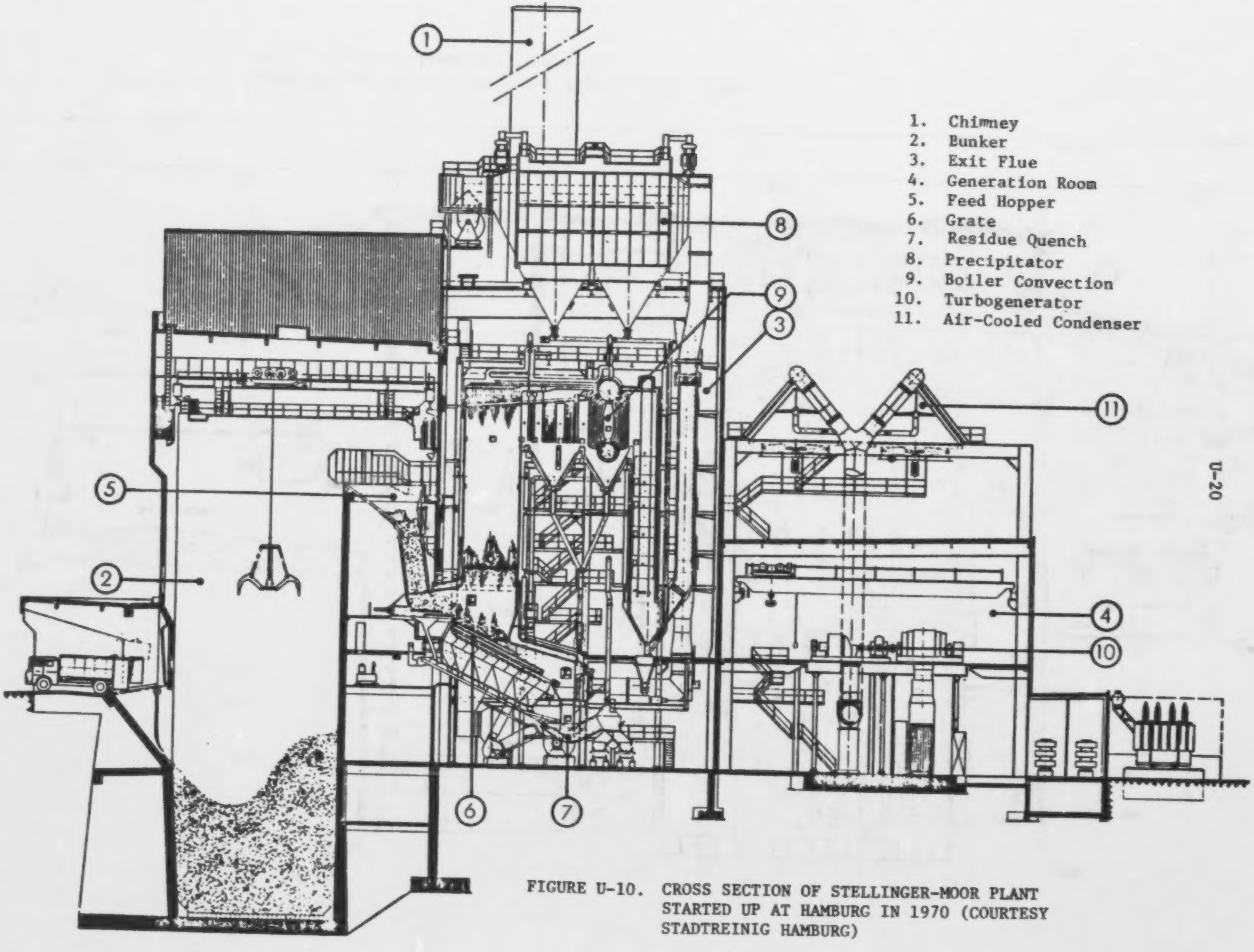

1
2
3
4
5
6
7
8
9
10
11
1. Chimney
2. Bunker
3. Exit Flue
4. Generation Room
5. Feed Hopper
6. Grate
7. Residue Quench
8. Precipitator
9. Boiler Convection
10. Turbogenerator
11. Air-Cooled Condenser

FIGURE U-10. CROSS SECTION OF STELLINGER-MOOR PLANT STARTED UP AT HAMBURG IN 1970 (COURTESY STADTREINIG HAMBURG) experience with refuse as fuel beginning in 1896 with 12 batch-fired units at Rohrstrasse equipped with waste-heat boilers. Accordingly, the two boiler-furnaces burning about 50 tonne/hr total at Stellinger-Moor incorporates the culmination of much valuable experience. However, the unexpected rise in heat value of the refuse at Hamburg, since the Stellinger-Moor plant was designed, has caused much difficulty with these two boilers. Hamburg plants have long had problems with low-heat value refuse. In fact, as described earlier, at the old Borsigstrasse plant, there was a time in 1960 when the heat value dipped so low that the fire went out.

Accordingly, the two present boilers were designed in 1968-1969 for a heat value of 1,500 kcal/kg (2,700 Btu/lb) (6,280 kJ/kg); but in 1974 to 1976, it was estimated to average 1,800 kcal/kg. Today, it is thought to average 2,500 kcal/kg. Industrial waste frequently pushes the value much higher with consequent overheating of the furnaces, superheaters, and precipitators. Thus, two methods of water injection have been used to alleviate this overheating:

(1) The refuse in the pit is sprayed with water when it is seen to be very dry, such as from masses of tobacco cuttings and bulk photographic film.

(2) Water is sprayed for cooling the gases ahead of the precipitator when the gas temperature approaches 350 C (662 F).

Water-Tube Walls. As described under "Furnace Wall", the sidewalls of the furnace are cooled by three large sloping headers on each sidewall. Then a welded membrane wall extends upward into the first pass.

Rising vertically above the combustion chamber is the open radiation-type first pass. Unlike the fin-tube membrane walls of the combustion chamber, these water-tube walls are not welded and have 20 mm (0.79 in) spacing between 70 mm (2.75 in) tubes.

As has been seen elsewhere, such unwelded tubes are free to bulge either out or into the radiation chamber depending on the type and intensity of thermal stresses.

An apparently improperly positioned and operating rotating wall soot blower blew a hole in a wall tube bulging out into the furnace midway up the first pass. It is believed that if the lower fin tubes of the combustion chamber were extended further up into the first pass, then the wall could have withstood further abuse from the soot blower before bursting. When the one tube burst, sections of 40 or 50 other wall tubes were replaced because of thinning due to corrosion. There has been metal wastage at other points and once per year, the thinning tubes are routinely replaced.

Stellinger-Moor is one of the last units to be built without welded membrane tube walls.

First Pass Roof Tubes. Sloping tubes form a roof at the top of the first pass which continues over the superheater section. These tubes carry saturated steam from the front water tube walls of the first pass directly to the boiler drum.

Fortunately, the management has had the foresight to make a detailed record of all measurements and everything done to the furnaces. A

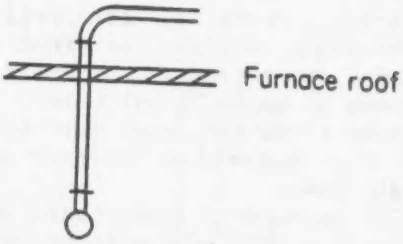
September 21, 1976, entry to the maintenance record reports on the roof tube problems.

The diameter of each tube is 25 mm (1 in) and the original wall thickness was 3.6 mm (.14 in). The measurements taken were only on tubes that had shown signs of metal wastage, i.e., tubes numbered 16 through 41. The wall thickness had been reduced from the original 3.6 mm (.14 in) down to between 1.6 and 2.3 mm (0.06 and 0.09 in). Of the 20 tubes measured, all but two tubes were replaced.

The corrosion of these sloping roof tubes was related to the high burning rates and to incomplete bonding of the SiC 90 that had been sprayed over metal studs on these large tubes. Because the tubes carry saturated steam at 290 C (483 F) and not the hotter superheated steam, the SiC refractory coating never was heated enough for proper bonding, i.e., 1,200 C (2,190 F).

The plant staff have decided to replace the SiC 90 by a high alumina plastic refractory. The superior heat transfer characteristics of a properly bonded SiC 90 will be sacrificed in favor of the cheaper and more reliable high alumina refractory.

Screen Tubes at Outlet of Radiation First Pass. All of the gases leaving the first pass go between the screen of tubes which carry the steam from the rear wall tubes over to the steam drum. These tubes depicted below have experienced erosion by the combustion gases.



The 18 tubes are 70 mm (2.76 in) in outside diameter and 3.2 mm (0.126 in) in thickness and widely spaced. The maintenance record book of September 8, 1976, shows that tube No. 10 in Boiler No. 1 burst and caused unit stoppage. Measurements were taken that showed an uneven pattern of greater metal wastage of the center tubes. As a result, five other thin tubes were also replaced. Early in 1977, all 18 tubes were removed and replaced with pipes having bolted shields.

As in other plants, this one has had good success in bolting Sicromal 10 shields usually 6 mm (0.15 in) thick to vulnerable tubes. The shields must usually be replaced every few months or years but this can often be done at regular down periods. Table U-1 shows the composition and characteristics of three Sicromal alloys.

Boiler Convection Section. The flue gases leave the superheater and continue flowing horizontally as they enter the boilers' convection

TABLE U-1. COMPOSITION OF SICROMAL STEEL USED FOR SHIELDING TUBES FROM HOT CORROSIVE GASES

Designation	Manufacturer	C	Si	Cr	Al	S	Tensile Strength				Yield Strength				Elongation		Reduction in Area		Common Uses
							at 20 C		at 800 C		at 20 C		at 800 C		at 20 C	at 800 C	at 20 C	at 900 C	
		%	%	%	%	%	psi	MPa	psi	MPa	psi	MPa	psi	MPa	%	%	%	%	
Sicromal 8	Vereinigte Stahlwerke, Duesseldorf	0.12 (max)	0.8	4-5	0.5	--	67,000	462	10,000	69	43,000	296	6,000	41	20	38	75	93	Superheater tubes, recuperator tubes.
Sicromal 9	"	0.12 (max)	1.2	13	1.0	0.005 (max)	78,400	541	11,400	79	40,000	276	7,200	50	15	50	68	90	Superheater and recuperator tubes, pipes, fittings.
Sicromal 10	"	0.12 (max)	1.0	18	1.0	0.005 (max)	85,200	587	14,500	100	50,400	347	7,200	50	10	53	63	98	Pyrometer tubes, anchor bolts, furnace parts.

Source: from Woldman - "Engineering Alloys" section. In this section, boiler-tube corrosion near the fixed position soot blowers had been a serious problem. As in many other plants, reducing the soot blower activity can provide increased tube life with no increase in costs. The only penalty is a modest decrease in thermal efficiency. Decreasing soot blower activity is recommended especially during seasons of "excess" steam production. Methods exist for reducing activity, frequency, and pressure for soot blowing.

First, as at Stellinger-Moor, many plants reduced the sootblowing frequency. In this case, many blowers that had been blowing once per shift are now schedueled to blow 1 to 3 times per week.

Secondly, the pressure has been reduced from 18 bars (1800 kPa) (261 psia) to 14 to 16 bars (1400 to 1600 kPa) (202 to 232 psia).

The plant staff pointed out that the actual setting of blowing frequency is a function of where the boiler is in its 4,000 hour cycle between major overhauls. In the first 1,000 hours, they blow only one third as often as before. If, however, they were in the last 1,000 hours, they blow half as much.

In the last 2 years that the changes have been made, they have experienced only five convection section tube failures per boiler, 10 in all. Four of the five tube failures were repaired in April, 1977. Detailed records are shown in the plant report to record maintenance activity. For each major section of the plant, a master sheet is prepared having a relevant standard sketch. These records for the April, 1977, repairs show the 20 tubes that were replaced because they were thin and shows the four tubes that burst.

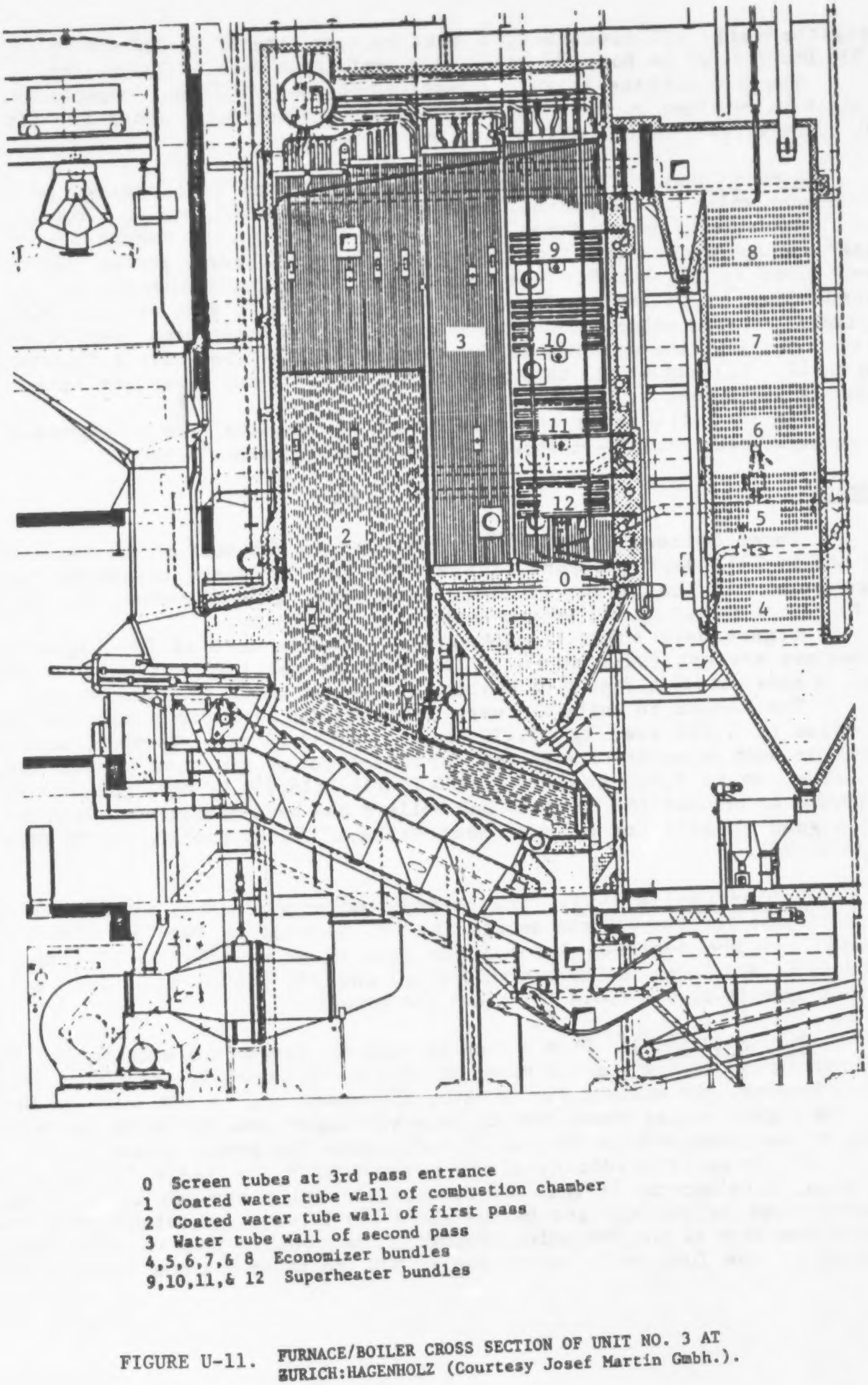
Thus, the overall experience at Stellinger-Moor is that: (1) unprotected water-tube wall tubes require partial replacement about once per year due to corrosion, (2) High alumina refractory coating or welded studs will protect tubes (3) the rapid increase of heat value of Hamburg refuse has intensified many problems arising from overheating of the boiler system, and (4) excessive use of steam-driven soot blowers causes corrosion by repeatedly exposing fresh metal surface to new corrosive deposits. This has been a common experience at many plants.

Zurich-Hagenholz

The unique features of the Hagenholz Boiler No. 3, by Martin, featuring two long, open water-cooled passes ahead of the superheater have already been mentioned. Figure U-11 shows another unique feature of this boiler in that the refractory covering on the studded wall tubes extends from the furnace up to above half the total height of the first pass. Thus, despite the fact that this boiler furnace is fired at an extremely high rate, the wall tubes have been protected from corrosive attack. The design philosophy expressed by the plant manager was that the refractory coating should extend 1 to 2 m (3.28 to 6.5 ft) above the level to which the furnace flames might be expected to reach.

Officials have been most pleased with results. After 30,000 hours, the exposed first pass wall tubes have experienced only 0.1 to 0.2 mm (0.004 to 0.008 in) metal wastage.

The temperature at the top of the furnace level with the front nose is 1,000 C (1832 F). Two-thirds up the first pass (where the SiC stops), the flue gas temperature falls to 800 C (1,472 F). Using the



0 Screen tubes at 3rd pass entrance
1 Coated water tube wall of combustion chamber
2 Coated water tube wall of first pass
3 Water tube wall of second pass
4,5,6,7,& 8 Economizer bundles
9,10,11,& 12 Superheater bundles

FIGURE U-11. FURNACE/BOILER CROSS SECTION OF UNIT NO. 3 AT ZURICH:HAGENHOLZ (Courtesy Josef Martin Gmbh.).

highly-thermally efficient SiC, a heat release rate of 94,000 Kcal/m^3-hr (10,530 Btu/ft^3-hr) is possible based on a heat input rate of 33 Gcal/hr.

The SiC surface is rarely repaired on the 1,000 hour inspections. SiC might be repaired on the 4,000 hour planned inspections. Studs and SiC might be repaired once per year during major overhaul.

Screen Tubes. A minor function of screen tubes is to better hold the furnace walls in alignment. A better flow of water is also a result. Also, at many plants screen tubes have a third function. At Hagenholz, to further reduce corrosion, flue gases pass between large, gently sloping screen tubes at the base of the third pass. Flue gas temperatures are reduced slightly to the benefit of superheater life. To some extent, these relatively easy-to-replace screen tubes are sometimes considered "sacrifice screen tubes". At the entrance to the third pass, the tubes have a diameter of 70 mm (2.8 in) and a wall thickness of 4.5 mm (0.18 in). They are spaced 300 mm (12 in) apart.

Figure U-11a shows the details of the various tube arrangements used at Hagenholz. Table U-1a shows typical gas temperature patterns.

The Hague

Three boilers installed in 1967-1968 by Von Roll at The Hague and a later one in 1972 depict a part of the evolution of waste-to-energy boiler design under (1) the impact of the rising heat value of refuse, and (2) the need to reduce resulting boiler and superheater corrosion.

Figure U-12 shows the two boiler designs used at The Hague. the superheaters are not fully shown in these cross-sections but will be shown later. A more detailed figure of Boilers No. 1-2 is shown in Figure U-13.

The furnace in Units 1-3 were designed in 1966 for a maximum lower heat value of 1,066 kcal/kg (3,270 Btu/lb) (8,653 kJ/kg). However, some dry, bulky waste such as wooden crates and cardboard boxes can have a much larger heat value, up to 4,000 kcal/kg (7,200 Btu/lb) (16,750 kJ/kg), and wetting of such refuse to protect the furnaces and boilers has been necessary. Unit No. 4 was designed in 1970 for a lower heat value of 2,500 kcal/kg (4,500 Btu/lb) (10,467 kJ/kg).

Boiler (Units 1-3). The overall boiler system was built in Holland under a license for the Eckrohr design by Dr. Verkauf of Berlin. The first three boilers are designed for a steam flow range of 18.8 to 37 tonnes/hr (41,360 to 81,400 lb/hr) at 40 bar (580 psia) and 425 C (797 F). The top of the steam drum is 20.9 m (68.4 ft) above the ground.

Boiler (Unit 4). This boiler is slightly larger and much taller than the first three, having a steam range of 18.8 to 40 tonnes/hr (41,360 to 88,000 lb/hr). However, the maximum firing rate, 15 tonnes/hr, is the same as Units 1-3. The higher rating comes from an expected higher heat value in the refuse. The top of the steam drum is 24.3 m (79.7 ft) above the ground floor.

In terms of predominant current practice for large furnaces, the Hague plant is noteworthy in that the furnace sidewalls are not water-cooled. The water-tube walled surface begins above the furnace and extends from there upward to the tope of the radiation chamber (first boiler pass). The sloping rear roof of the furnace is water-cooled but the tubes are completely covered

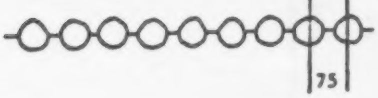
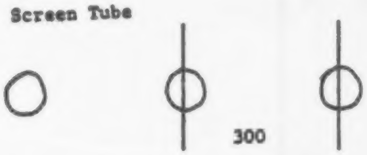
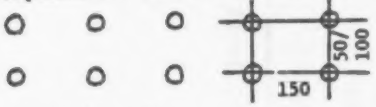
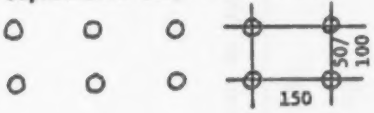
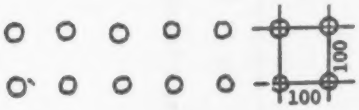
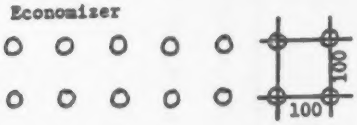
		Tube Diameter mm	Tube Thickness mm	Flue Gas Velocity Maximum	Average
Water Tube Walls 1st and 2nd Passes 	1st Pass	57	4.0	4.38	4.10
	2nd Pass	57	4.0	6.66	6.40
Screen Tube 		70	4.5	5.55	5.55
Superheater (Lower first bundle)  serpentine tubes		31.8	4.0	6.65	6.45
Superheater (Top three bundles)  serpentine tubes		31.8	4.0	6.25	5.75
 serpentine tubes		38	4.0	7.00	6.45
Economizer 		38	4.0	6.10	5.5

FIGURE U-11a. BOILER TUBE SECTIONS LAYOUT AT ZURICH: HAGENHOLZ #3

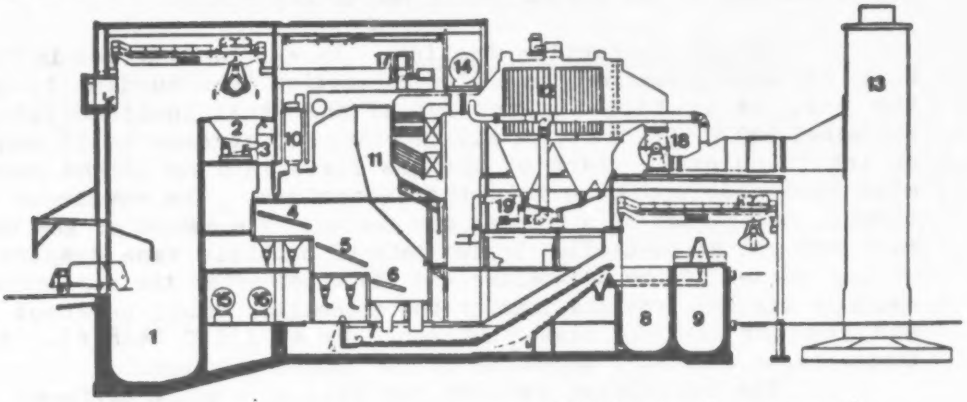
TABLE U-1a. FLUE GAS TEMPERATURES, CO_2 LEVELS, AND STEAM FLOW RATES RECORDED ON JUNE 9, 1977 AT ZURICH: HAGENHOLZ UNIT #3

	First Pass Furnace Roof		Superheater Section				Economizer			
	Left	Right	Before Hottest Bundle	Before 3rd Bundle	Before 2nd Bundle	Before 1st Bundle	Before Economizer	After Economizer	CO_2 (%)	Steam Flow Tonnes/2 hr
1 a.m.	860	860	720	680	630	510	530	290	10	--
3 a.m.	740	780	720	690	640	510	540	287	9	73
5 a.m.	680	630	630	600	560	460	500	275	9.5	70
7 a.m.	780	790	730	700	640	510	540	285	9	72
9 a.m.	730	800	690	670	630	500	540	285	9	66
11 a.m.	730	760	710	690	640	510	540	285	11	71
1 p.m.	730	760	700	670	630	500	535	282	11	69
2 p.m.	730	750	700	680	635	500	540	290	8.2	71

Readings taken by Battelle researcher from charts and graphs on the day in question.

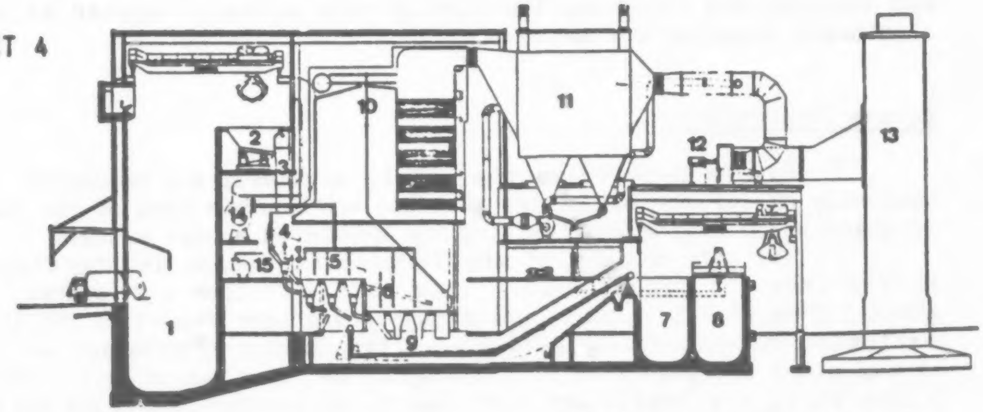
This Unit #3 had been cleaned 3,000 hours previously.

THE HAGUE UNITS 1, 2, 3 LONGITUDINAL SECTION



1 Refuse pit
2 Vibrating hopper
3 Feed chute
4 Feed grate
5 Main grate
6 Burnout grate
7 Clinker channel
8 Clinker pit
9 Settling tank
10 Combustion chamber
11 Boiler
12 Electrostatic precipitator
13 Stack
14 Feed water tank
15 Additional water tank
16 Condensate tank
17 Forced draft fan
18 Induced draft fan
19 Flue gas recycling fan

THE HAGUE UNIT 4



1 Refuse pit
2 Vibrating hopper
3 Feed chute
4 Feed grate
5 Main grate
6 Burnout grate
7 Clinker pit
8 Settling tank
9 Clinker channel
10 Boiler
11 Electrostatic precipitator
12 Induced draft fan
13 Stack
14 Forced draft fan
15 Overfire air fan

FIGURE U-12. COMPARATIVE CROSS-SECTIONS OF THE TWO BOILER-FURNACE SYSTEMS AT THE HAGUE PLANT. UNITS 1-3 WERE DESIGNED IN 1965. UNIT 4 WAS DESIGNED IN 1971. (Courtesy of Gemeentelijk Energiebedrijf Vuilverbranding)[Waste-burning Energy Utility] by formed refractory block supported between the tubes. Thus, there is very little cooling of the predominantly refractory furnace.

Boiler Convection Section. As can be observed in Figures U-12 and U-13, the arrangement of the boiler convection tube bundles is unique in that the gas, as it flows upward out of the first inclined tube bundle at an estimated 600 C (1,112 F), is divided into two streams as it continues upward in the third pass. Part of the gas flows into the second convection bundle, also inclined, and then into the economizer. The remainder flows upward through two passes of a tubular air heater. The amount of gas that flows along each path can be controlled by two sets of multiple vane dampers, one located at the outlet of the economizer and the other after the air heater. The design estimate was that the gas leaving the economizer would be about 315 C (600 F) and leaving the air heater it would be at 220 C (428 F). Actually these temperatures will vary depending on the damper settings.

The convection section for Unit 4 is quite different from Units No. 1-3 as can be seen by comparing them in Figure U-12. The second pass is a completely open water-tube-walled down-pass with the superheater banks horizontal across the bottom of the third pass and thus far removed from the furnace. The air heater was eliminated in Unit No. 4 and the third pass contains not only the superheaters but also the two evaporator bundles and two tubular economizers.

It appears that the slagging and corrosion problems that have occured at The Hague have been caused primarily by the rapid increase in heating value of the local refuse. The addition of overfire air jets plus wall-tube studding and coating and reducing the firing rate somewhat appear to have largely eliminated slagging and corrosion.

Dieppe (Deauville)

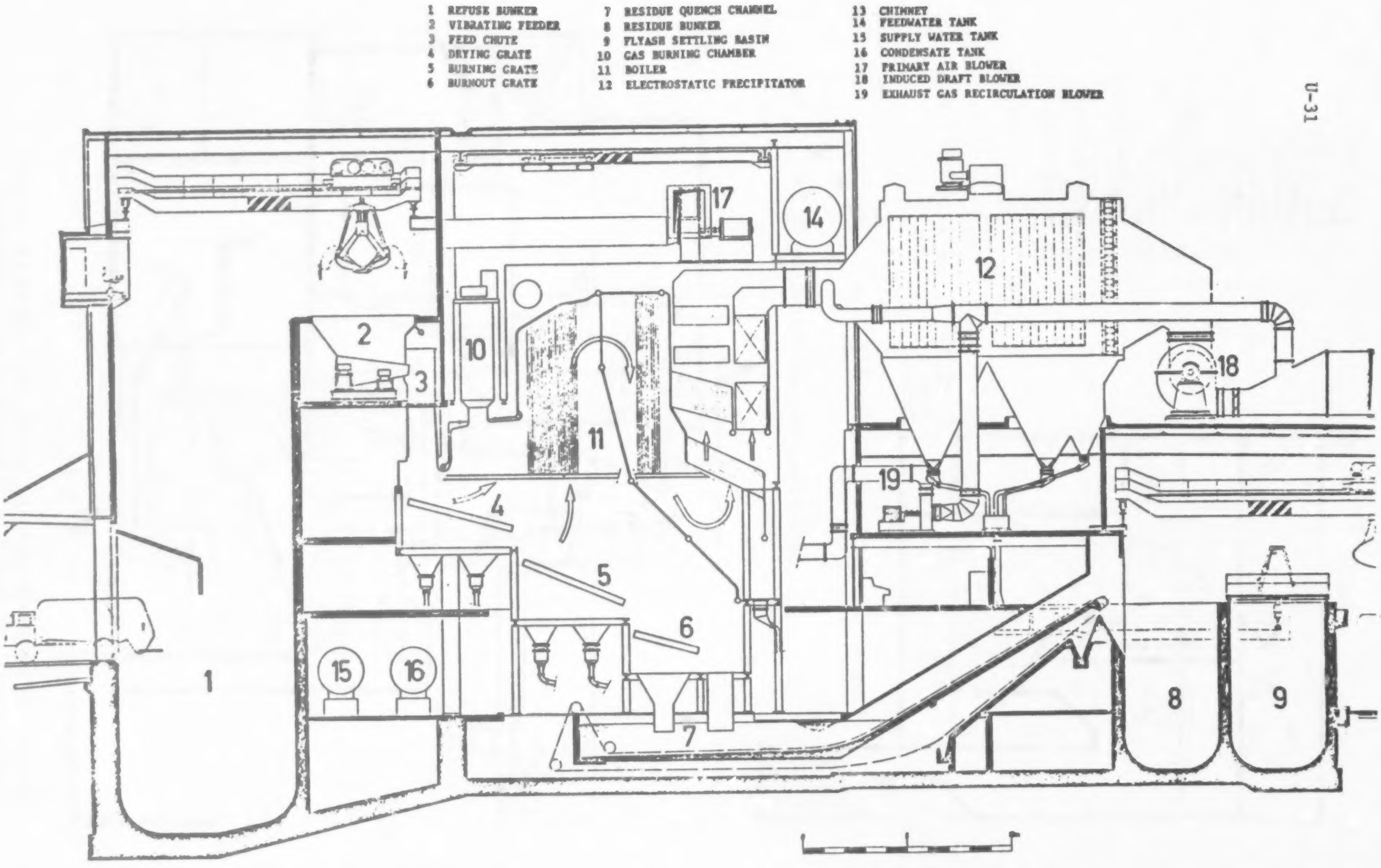
Figure U-14 shows the plants at Dieppe and Deauville, France, which need only relatively small fire tube boilers because most of the heat generated is absorbed in drying and igniting the dewatered sewage sludge.

The only cooling of the furnace at Dieppe is the diagonal furnace baffle shown in Figure U-14. This baffle is formed of spaced, sloping tubes about 120 mm (4.7 in) apart, which supports bricks shaped to fit the tubes. An estimated 100-150 C (180-270 F) gas temperature drop occurs as the gases flow upward along the underside of the sloping baffle than pass through the spaced tubes above the baffle and turn toward the vertical firetube boiler inlet. It is estimated that about one sixth of the total heat is absorbed by the baffle.

At Deauville, designed about 5 years later, there is no water-cooled baffle. The furance volume is also much less than at Dieppe, which is about 80 m^3 (2,823 ft^3), and the furnace gases at Deauville pass directly to the vertical firetube boiler.

The use of refractory instead of water-tube walls entails some loss of thermal efficiency but this loss is not important at either plant so long as there is ample steam generated to dry the sludge.

Each furnace has a 6-million calorie/hr oil burner, but they are never used.


1 REFUSE BUNKER
2 VIBRATING FEEDER
3 FEED CHUTE
4 DRYING GRATE
5 BURNING GRATE
6 BURNOUT GRATE
7 RESIDUE QUENCH CHANNEL
8 RESIDUE BUNKER
9 FLYASH SETTLING BASIN
10 GAS BURNING CHAMBER
11 BOILER
12 ELECTROSTATIC PRECIPITATOR
13 CHIMNEY
14 FEEDWATER TANK
15 SUPPLY WATER TANK
16 CONDENSATE TANK
17 PRIMARY AIR BLOWER
18 INDUCED DRAFT BLOWER
19 EXHAUST GAS RECIRCULATION BLOWER
1
2
3
4
5
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7
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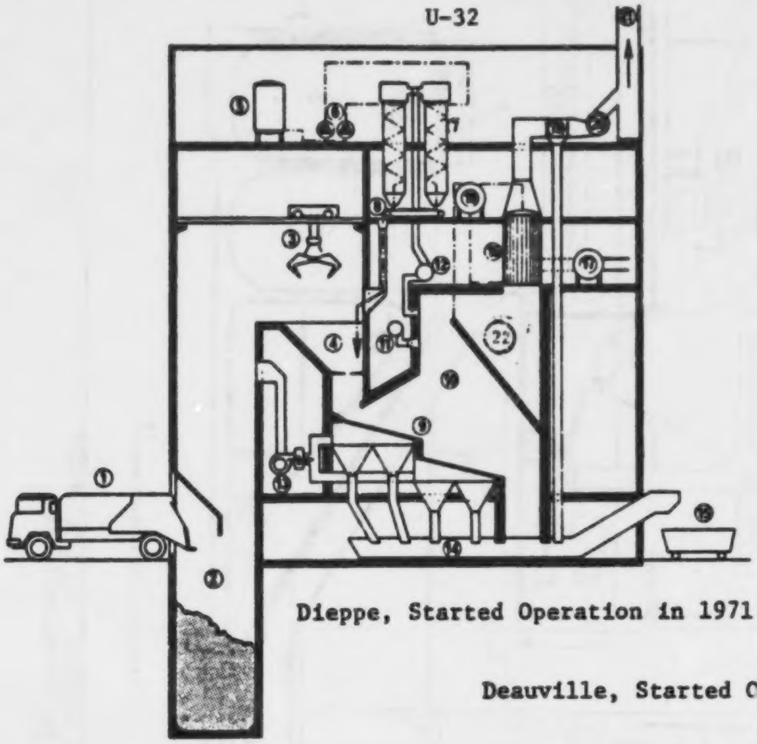
19

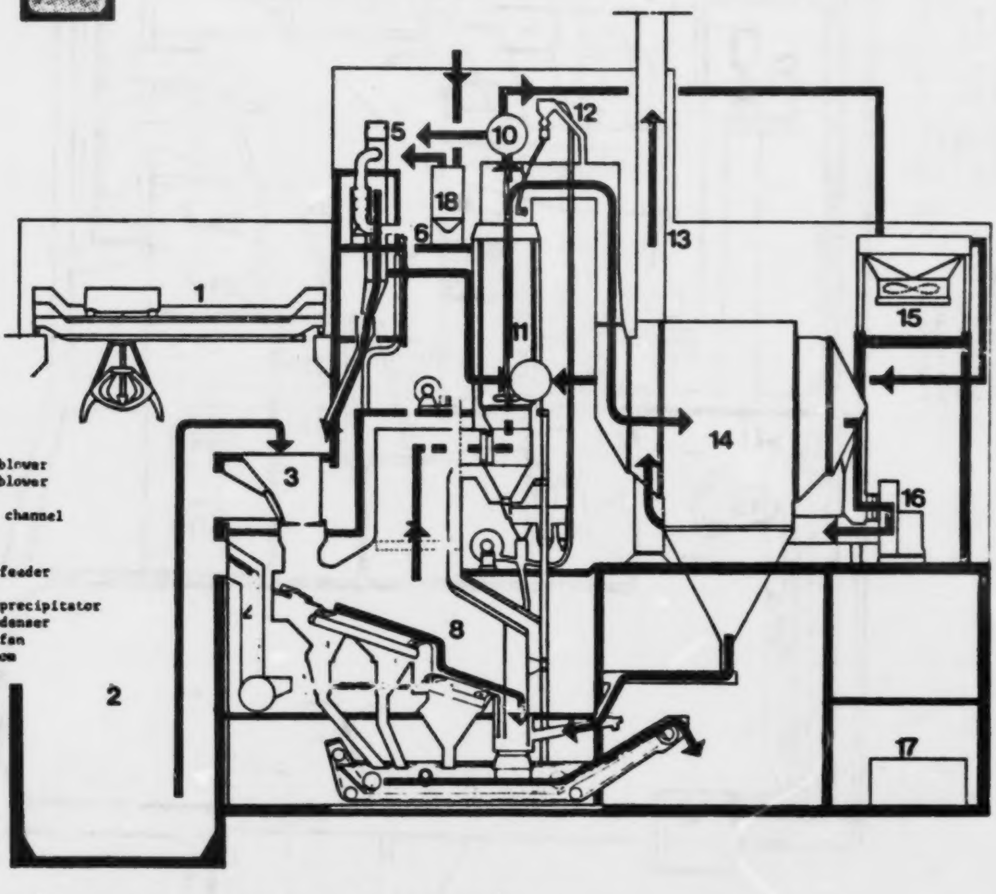
FIGURE U-13. CROSS-SECTION OF BOILER SYSTEMS, 1-3 THE HAGUE
(Courtesy of Gemeentelijke Reinigindienst)



1. Outdoor tipping area
2. Refuse pit
3. Crane and bucket
4. Feed hopper
5. Sludge storage tank
6. Sludge pumps
7. Sludge dryers
8. Dried sludge conveyor
9. Incineration grates
10. Furnace
11. Oil burner
12. Blower for dryer vapors
13. Primary air blower
14. Residue quench channel
15. Residue cart
16. Boiler
17. Water-cooled condenser
18. Steam drum
19. Dust collector
20. Induced draft fan
21. Chimney
22. Cooling Baffle

Dieppe, Started Operation in 1971

Deauville, Started Operation in 1976



1. Crane
2. Refuse bunker
3. Feed hopper
4. Water storage
5. Sludge dryer
6. Dryer exhaust blower
7. Secondary air blower
8. Furnace
9. Residue quench channel
10. Steam drum
11. Boiler
12. Shot cleaning feeder
13. Chimney
14. Electrostatic precipitator
15. Air-cooled condenser
16. Induced draft fan
17. Transformer room
18. Sludge storage

FIGURE U-14. COMPARATIVE CROSS SECTIONS OF DIEPPE AND DEAUVILLE REFUSE-BURNING PLANTS (COURTESY OF CITIES OF DIEPPE, DEAUVILLE, AND VON ROLL, LTD. AND INOR S.A.)

The vertical boilers at Dieppe were built by Sacoma with a heating surface of 240 m^2 (2,582 ft^2). They are 6 m (19.7 ft) tall and 1.8 m (5.9 ft) outside diameter. The 387 tubes are 52 mm (2 in) inside. The boilers were designed to produce 7.5 tonne/hr (15,510 lb/hr) of steam at 16 bar (1,600 kPa) (232 psia). The saturated steam temperature is 180 C (356 F). Actually the boilers operate at a pressure of about 10 bar (1,000 kPa) (145 psia) and an output of 6.5 tonnes/hr (14,000 lb/hr). Feedwater temperature is 140 C (284 F).

Design gas flow rate was 22,000 Nm^3/hr (12,947 scfm). The flue gas temperature leaving the boiler was about 350 C (662 F) when the plant started up. However, it was found necessary to inject 5,000 m^3/hr (2,943 cfm) of secondary air by means of six nozzels located in the front wall. This air diluted the flue gas and caused the boiler exit gas temperature to drop to about 280 C (536 F). Such a high exhaust temperature represents a substantial thermal loss but since there is ample heat for drying the sludge and, at present, no other use for the heat, the loss is not serious for this particular plant.

Every 3 months, each biler is drained and comnpletely cleaned internally and externally by the plant staff using brushes and other small tools.

Gothenburg-Savenas

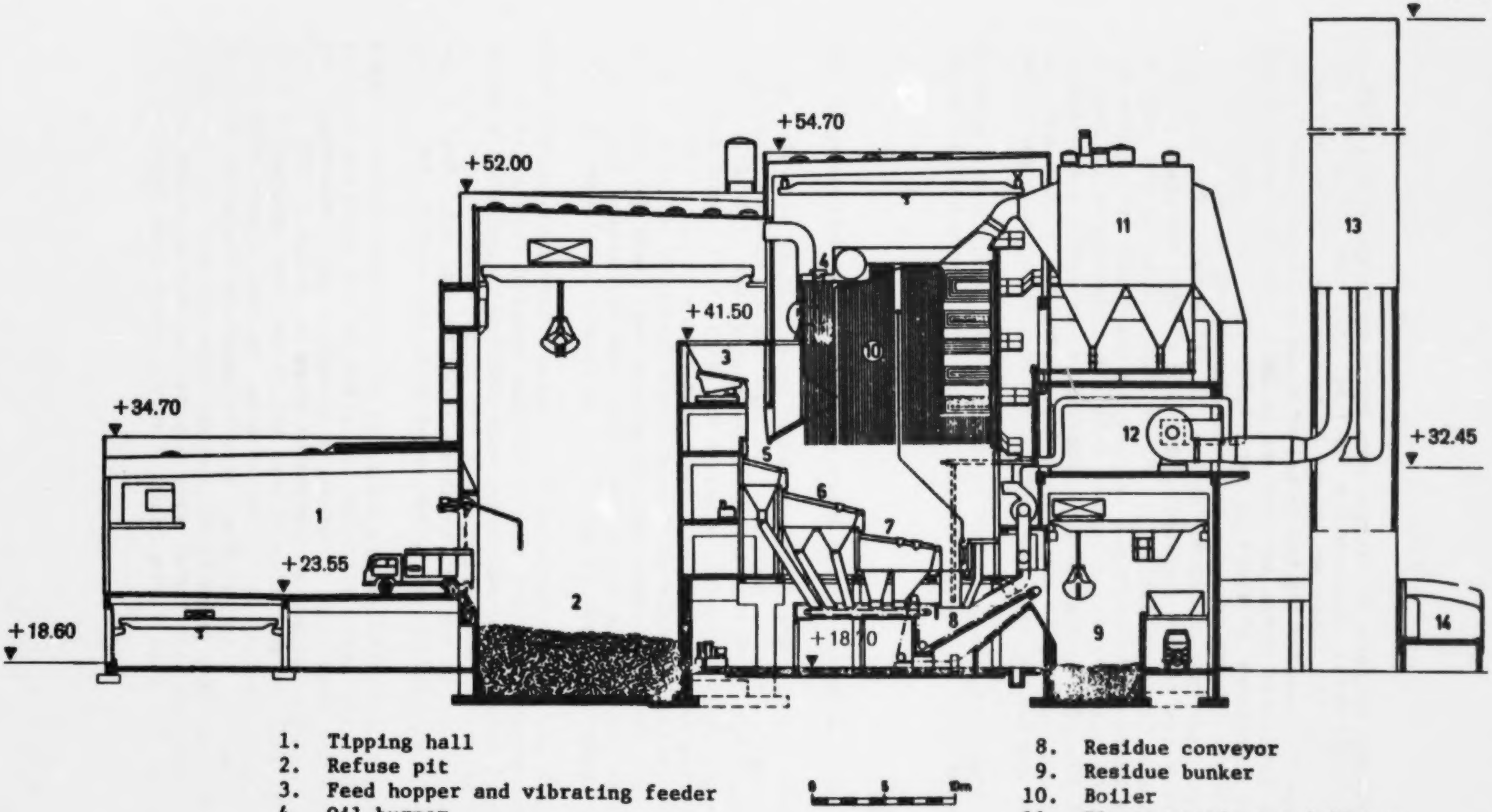
Figure U-15 shows one of the three boilers built at Gothenburg by Von Roll in 1971.

The three boilers are of the Eckrohr type built by Generator AB of Gothenburg under license from Dr. Verkauf of Berlin. Rated steam capacity is 52.5 tonnes/hr (115,500 lb/hr) of saturated steam at 22 bar (313 psia) (2,157 kPa). Overall height is 13 m (42 ft), width is 4.5 m (14.8 ft), and depth is 15.5 m (51 ft). There is no economizer. Steam temperature is 217 C (423 F).

This is another example of fairly large furnaces which are not water-tube walled. The water-tube wall is seen to begin near the top of the furnace at about the level of the top of the refuse feed entrance. The carbon steel tubes are tangent welded, 76 mm (3 in) in diameter, and 4 mm (0.16 in) thick.

The front and rear furnace walls are spaced water tubes covered with refractory. This minimal cooling of the furnace coupled with a period of unusually high heat value of the refuse may have combined to aggravate slagging and roof tube problems. Above the nose of the front wall can be seen a separate water-tube-walled combustion chamber for burning oil. Half of the rated heat output of each boiler can be generated using low-sulfur, No. 5 fuel oil.

Originally, each boiler was equipped with 21 soot blowers. There were two sets in the first pass. Although the plant is for district heating only (hence, does not need high-temperature steam), a small superheater was placed in the third pass to generate superheated steam up to 300 C (572 F) for soot blowing only. When the soot blowers were not in use, the superheated steam is condensed in a heat exchanger in the boiler drum. The soot blowers thus were assured of dry steam so as to avoid any erosive impact on the boiler tubes by water droplets. However, they probably cleaned the tubes too well and too often with the result that the bare tubes were exposed to corrosion and probably erosion. In 1974, it had been first noted that the first pass blowers were


+52.00
+54.70
+41.50
+34.70
+23.55
+18.60
+18.10
+32.45
1
2
3
4
5
6
7
8
9
10
11
12
13
14
0
5
10m

1. Tipping hall
2. Refuse pit
3. Feed hopper and vibrating feeder
4. Oil burner
5. Reciprocating feed grate
6. Burning grate with grate "knives"
7. Burnout grate with grate "knives"
8. Residue conveyor
9. Residue bunker
10. Boiler
11. Electrostatic precipitator and multicyclone collector
12. Induced draft fan
13. Chimney
14. Entrance ramp

FIGURE U-15. CROSS SECTION OF NOMINAL 900 TONNE PER DAY. REFUSE FIRED STEAM-TO-HOT WATER HEATING PLANT AT SÄVENÄS, GOTHENBURG. PLANT STARTED UP MARCH 1, 1972. (COURTESY OF VON ROLL, LTD.)

cleaning exceptionally well. Accordingly, 11 of the 21 blowers have now been removed and the 10 remaining are used less frequently.

Some wastage has occured in the roof tubes of both the first and second pass. This is being countered by a sprayed-on coating of silicon carbide about 8 mm (0.31 in) thick. The same coating has been sprayed opposite the soot blowers in the second pass. The durability of this coating appears good after 1 year but has not yet been fully determined.

Ten sections of alloy-clad steel tubes are being tried in the upper middle position of the wall of the second pass. These "sandwich" tubes, made by Sandviken, have a wall thickness of 7.1 mm (0.28 in) and are coated with an extruded stainless steel layer which is 1.6 mm (0.063 in) thick. Although these tubes cost 10 times as much as carbon steel tubes, experience with an entire pass formed of these tubes at the Hogdalen plant, built by Vereinigte Kesselwerke of Duesseldorf south of Stockholm, indicates that for conditions at that plant they are worth the cost in minimizing tube wastage.

To monitor first pass gas temperature, thermocouples have been placed about 7 m (23 ft) above the grate.

In the third pass, which contains the boiler convection sections and superheater, some tube erosion by soot blowers has occurred. This was first countered by means of alloy half-round shields 1 mm (0.40 in) thick made of Swedish steel designated 23-43. The shields were tack welded to the tubes directly opposite the soot blowers. For simplicity, these were later replaced by alloy angle irons strapped to the tubes. The angles are made of 20 percent chromium and 10 percent nickel steel. This material costs 40 skr/kg ($3.60/lb). They are fully successful in protecting the tubes from soot-blower action and appear to survive about 6 months before requiring replacement.

There is some evidence of slag accumulation on the refractory walls. As changes were made in wall-tube coatings and secondary air direction, this slag appeared to accumulate higher up on the walls. Some thought is being given to the possible use of air-cooled wall blocks low in the furnace to help alleviate this problem.

Second Pass. All of the wall coatings, roof coatings, and convection-bank shielding have impaired somewhat the total boiler heat absorption. To counter this loss, it is planned shortly to install in the second pass three vertically suspended plattens of water tubes to increase heat absorption in that pass.

Uppsala

The Uppsala waste-to-energy plant is a part of a much larger environmental improvement and energy conservation program that was started by the City Council in 1960.

The first delivery of heat was in August, 1961, from a portable oil-fired boiler, and the first permanent oil-fired hot water generator at the Kvarngarde Plant began operating in September, 1962. Since then, expansion has materialized into a larger oil-fired hot water station in the Bolanderna Plant and in the waste incineration plant, which began operating at Bolanderna in 1961 where the steam produced is used to heat water for district heating. The initial installation of two furnaces rated at 3 tonnes/hr and supplying hot gas to two waste heat boilers was built in 1960 by Kochum-Landsverk and began operation in 1961. A third similar but larger (3.5 tonne/hr) was added in 1965. A fourth furnace system, burning 5 tonnes/hr and feeding a third boiler, began operation in 1970. This newer installation, built by Bruun and Sorensen, the principal subject for the report on this plant, is shown in Figure U-16.

As with many small refuse-fired furnaces, these four furnaces are not water cooled. Their completely refractory construction has been satisfactory except for a major error in installation of too-widely spaced support anchors in Furnace No. 4. This has caused much breakage and some occasional collapse of firebrick. This has now been corrected.

All three boilers serving the four refractory furnaces are water-tube boilers producing saturated steam at 15 bar (217.6 psia) (1,500 kPa). Saturation temperature is 138 C (389 F). The first two boilers use forced circulation. Boiler No. 3, built by Maskinverken, Kallhall, Sweden, under a license from Combustion Engineering Co. of Windsor, Connecticut, U.S.A., uses natural circulation. The boiler steam capacities are:

	tonne/hr	lb/hr
No. 1	10	22,000
No. 2	15	33,000
No. 3	15	33,000
TOTAL	40	88,000

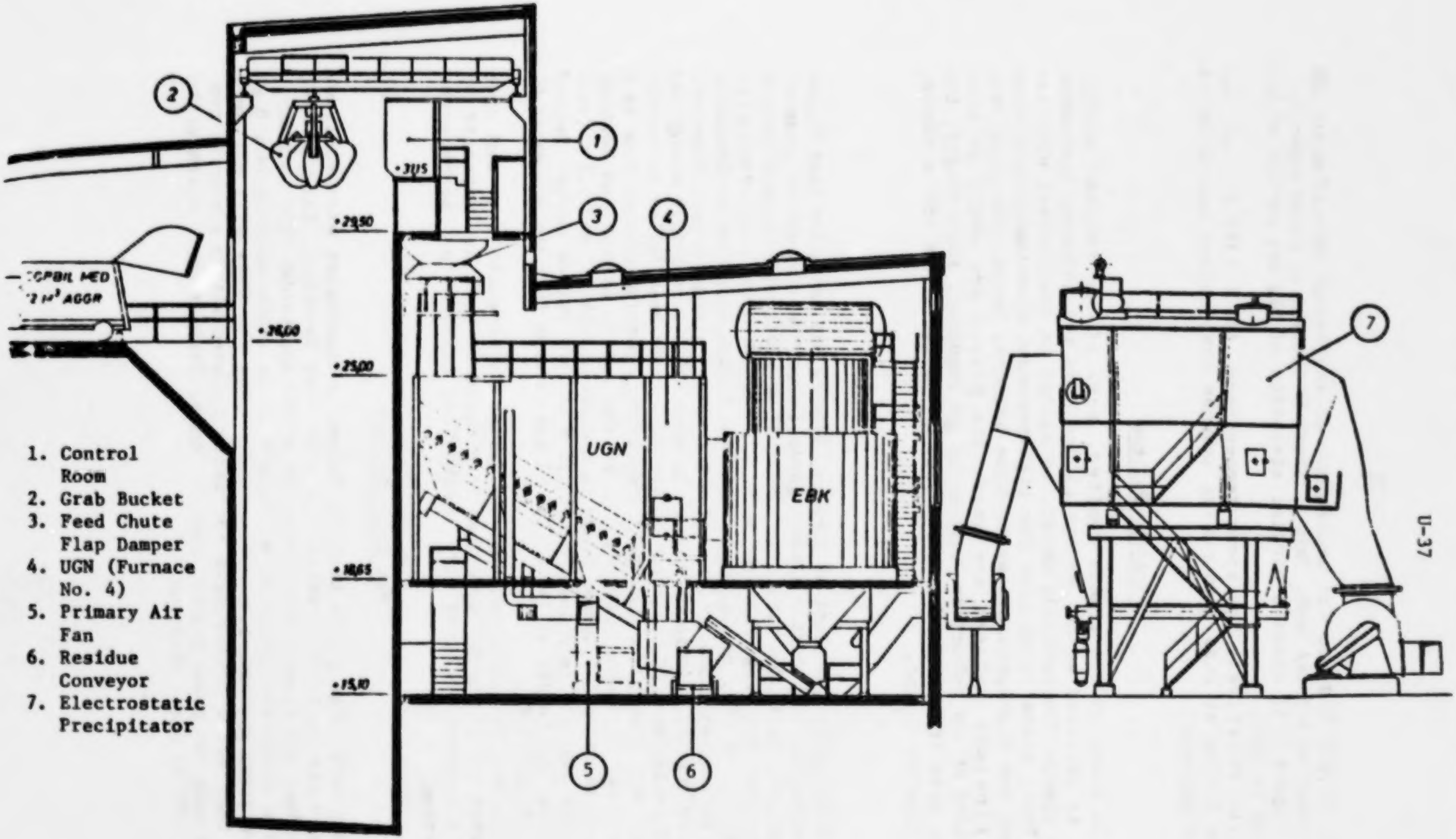
The three boilers and four furnaces are cross manifolded so that various combinations can be operated. However, all three boilers and all four furnaces are rarely operated all at the same time.

Boiler No. 3, the newest boiler, is formed of an outer enclosure of wall tubes plus banks of horizontal convection tubes. It receives hot gases from a cyclonic after-combustion chamber.

The maximum gas temperature entering the boiler is about 700 C (1,292 F). Incidentally, with 1,000 C leaving the furnace and 700 C entering the boiler, this 300 C cooling represents a substantial energy loss in passing through the after combustion chamber but, at the same time, that cooling undoubtedly contributes to the slag-free, trouble-free operation of that chamber as a gas mixing, burning, and dust removal device. The nominal capacities of the components are as follows:

	tonnes/hr	tons/hr	tons/day
Furnace No. 1	3.0	3.3	72
Furnace No. 2	3.0	3.3	84
Furnace No. 3	3.5	3.9	84
Furnace No. 4	5.0	5.5	108
TOTAL REFUSE CAPACITY	14.5	16.0	348
Boiler No. 1	10.0	11.0	--
Boiler No. 2	15.0	16.5	--
Boiler No. 3	15.0	16.5	--
TOTAL STEAM CAPACITY	40.0	44.0	88,000 lb/hr

However, these total capacities are only ratings as the plant was not intended to and never operates all components at full capacity. Usually some components are down for service. The actual average plant burning rate


UGN
EBK
+31,15
+29,50
+26,60
+25,00
+18,65
+15,10
1
2
3
4
5
6
7

1. Control Room
2. Grab Bucket
3. Feed Chute Flap Damper
4. UGN (Furnace No. 4)
5. Primary Air Fan
6. Residue Conveyor
7. Electrostatic Precipitator

FIGURE U-16. CROSS SECTION OF FURNACE NO. 4 AND BOILER NO. 3 AT UPPSALA (COURTESY OF BRUUN AND SORENSEN) for 1976, 51,000 t/d was the equivalent of an average rate of about 200 tons/day based on a 5-day week. This is about 52 percent of rated capacity.

Figure U-17 shows a partial elevation of the new portion of the plant added in 1971.

The relatively low steam temperature, 198 C (389 F), and the customary firing at less than rating assures that boiler corrosion is avoided at Uppsala.

Firetube Boilers

In three of the plants visited, most of the thermal energy released is utilized to dry sewage sludge from the adjacent wastewater treatment plants. The partially dewatered sludge is then burned with the refuse. Thus, there is no need for high-pressure, high-temperature steam and no need for high-pressure water-tube boilers. Hence, the much less costly firetube boilers are used. The plants are small so that water-cooling of the refractory furnaces is not required. Accordingly, the hot gases pass from the refractory-walled combustion system into a simple, vertical firetube boiler.

Horsens

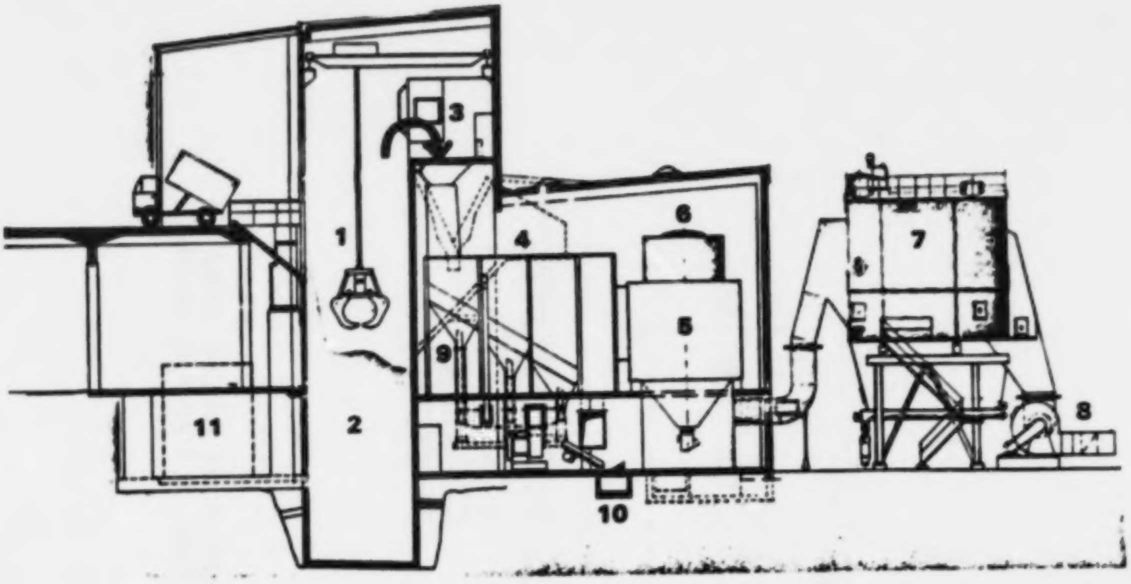
Originally the plant at Horsens, Denmark had no boiler (see Figure U-18). Instead the hot, partly cleaned gases leave the combustion chamber at two points. From the top, they could flow vertically upward into a water-sprayed cooling chamber and, hence, to the electrostatic precipitator; or they could leave from the bottom hopper or horizontally through a refractory-lined duct to enter the rotary sludge dryer. However, the growing urgency throughout Denmark to conserve all available energy led in 1977 to replacement of the spray cooler by a waste heat boiler to supply hot water, not steam, for the existing district heating system. This is a simple vertical firetube boiler built by the Danish Stoker and Heating Company. It contains 540 tubes, 57 mm in diameter (2.25 in) and 4.5 m (14.8 ft) long. Its capacity is 7 Gcal/hr (27,776 M Btu/hr) 29.308 GJ/hr. Heated water leaves the boiler at 110 C (230 F) and returns from the system at 80 to 90 C (176 to 184 F).

The top (exhaust) end of the boiler is accessible so that once every 2 weeks all of the 540 tubes can be cleaned of soft ash deposits by means of a powered rotating wire brush. This takes 6 to 7 hours every Monday morning.

Hot Water Boilers

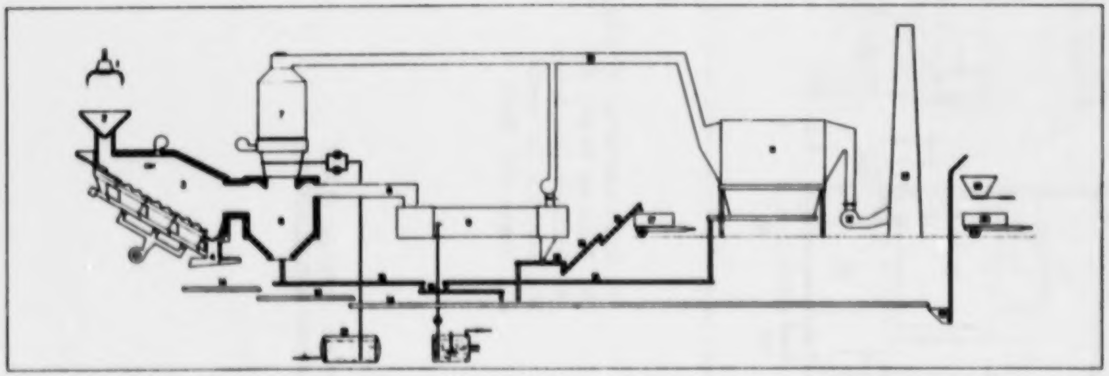
Two very large plants built by Volund in Copenhagen were visited. They generate only hot water for district heating. Each plant, Copenhagen-Vest and Amager, has a capacity of 864 tonnes/day (950 tons/day).

The corporate position of Volund is to avoid building very high temperature steam systems, i.e., above 450 C (842 F). They will not sell anything that would likely have corrosive failures within a year or two. Volund has only two steam plants, both in Japan. They produce steam up to the 350 C (662 F) level required.



1. Crane and Bucket
2. Refuse Bunker
3. Crane Operator's Station
4. Furnace
5. Afterburner Chamber
6. Steam Boiler
7. Electrostatic Precipitator
8. Induced Draft Fan
9. Primary Air Zones
10. Residue Conveyor
11. Waste Oil Tank

FIGURE U-17. ARRANGEMENT OF UPPSALA PLANT
(COURTESY BRUUN AND SORENSEN)



1. GRAB
2. RECEPTION HOPPER
3. FURNACE
4. SLAG DISCHARGE
5. COMBUSTION AIR
6. AFTER-COMBUSTION CHAMBER
7. COOLING TOWER
8. COMBUSTION-GAS DUCT TO ROTARY DRYER
9. ROTARY DRYER
10. COMBUSTION-GAS DUCT FROM ROTARY DRYER AND COOLING TOWER.
11. ELECTROSTATIC PRECIPITATOR
12. EXHAUST FAN
13. CHIMNEY
14. SLAG VIBRATION CONVEYOR
15. SCREW CONVEYOR FOR FLY ASH
16. SCREW CONVEYOR FOR DRIED SLUDGE
17. CONTAINER FOR DRIED SLUDGE
18. SKIP HOIST FOR SLAG
19. SLAG BUNKER
20. SLAG CONTAINER
21. COOLING WATER
22. SLUDGE CONTAINER

FIGURE U-18. SCHEMATIC OF ORIGINAL HORSENS PLANT WITH WATER SPRAY COOLING TOWER (LATER REPLACED WITH WASTE HEAT RECOVERY BOILER OF FIRE-TUBE DESIGN-COURTESY BRUUN AND SORENSEN).

The West and Amager plants, both built in 1969 have Eckrohr vertical water-tube wall boilers completely separate from and following the combustion furnace. Figure U-19 shows these plants. The furnaces are refractory followed by water-walled boilers, i.e., Volund units are not "water-tube wall incinerators". The Eckrohr boilers were built under a license from Professor Dr. Vorkauf of Berlin, W. Germany.

Figure U-20 is included to better show the water tube boiler although it depicts the Moscow plant built in 1975-1976. The boiler consists of four vertical water-tube walled passes which are completely separate from the combustion chamber and rotary kiln.

When asked why the Eckrohr boiler was used instead of the routinely specified Volund boiler, the reply evoked the Eckrohr features--features that seemed popular in several other places in Europe:

- The four corner tubes are used not only to carry down- stream water but also provide the structural support for the whole boiler, thus reducing construction costs.
- The heat transmission is excellent.
- The circulation pattern is good.
- It has high efficiency.
- It is a natural circulation boiler.

The market for energy demands slightly higher temperatures at West than at Amager as follows:

Energy Form	West "superheated" water	Amager hot water
Water temperature leaving plant	160 - 170 C	115 - 120 C
Water temperature returning to plant	140 C (284 F)	70 C (158 F)
Heat output	21.5 Gcal/hour	20 Gcal/hour
Pressure (working)	16 kg/cm^2 (225 psi)	6 kg/cm^2 (85 psi)

The key reason for higher temperatures at West is that an early customer was the Copenhagen County Hospital that needed hotter water for steriliztion and air conditioning.

The combustion gas inlet temperature to the boiler is around 800 C (1472 F). The outlet combustion gas temperature range from 280 to 350 C (536 to 662 F).

The boiler of Unit No. 4 at the West plant has 54 percent more heating surface area than each of the Units No. 1-3: 1,713 m^2 (18,432 ft^2) compared to 1,115 m^2 (12,000 ft^2).

A "Scott Wall", not found in many boilers, is a wall of tubes in the middle of a pass. Its purpose is to absorb more heat, to help reduce gas temperature, to increase residence time, and to redirect flue gases to the hoppers so that more fly ash is dropped out.

Plant staff have been happier with Volund's Unit No. 4. It can process 14 tonnes (15 tons) of refuse per hour. The dust accumulation on

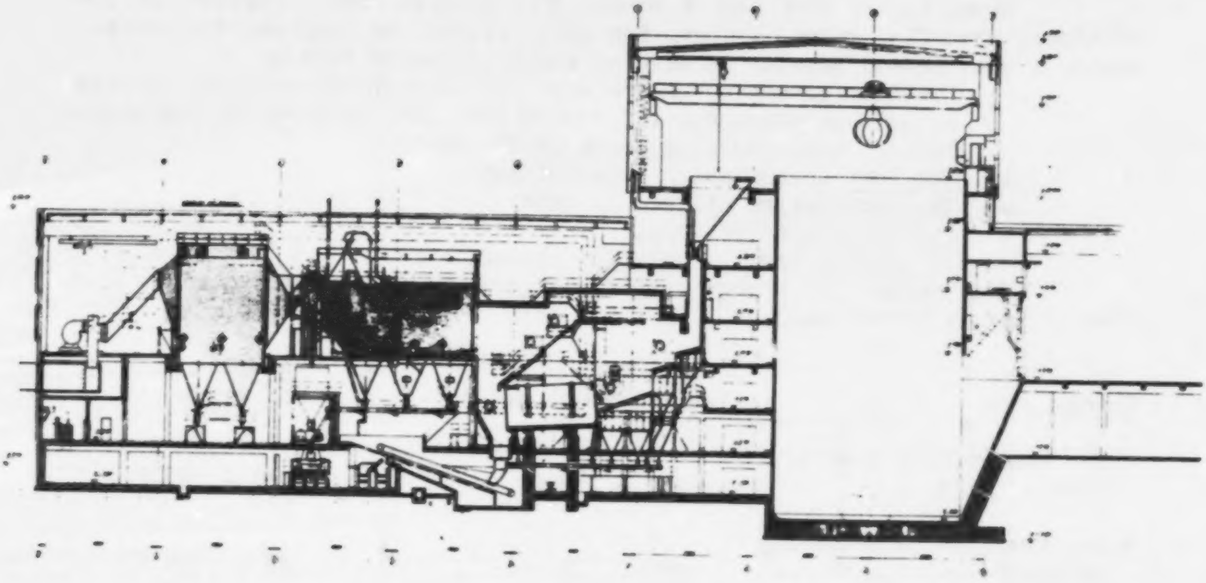


FIGURE U-19. ENGINEERING DRAWING OF COPENHAGEN: AMAGER (Courtesy Of Volund)

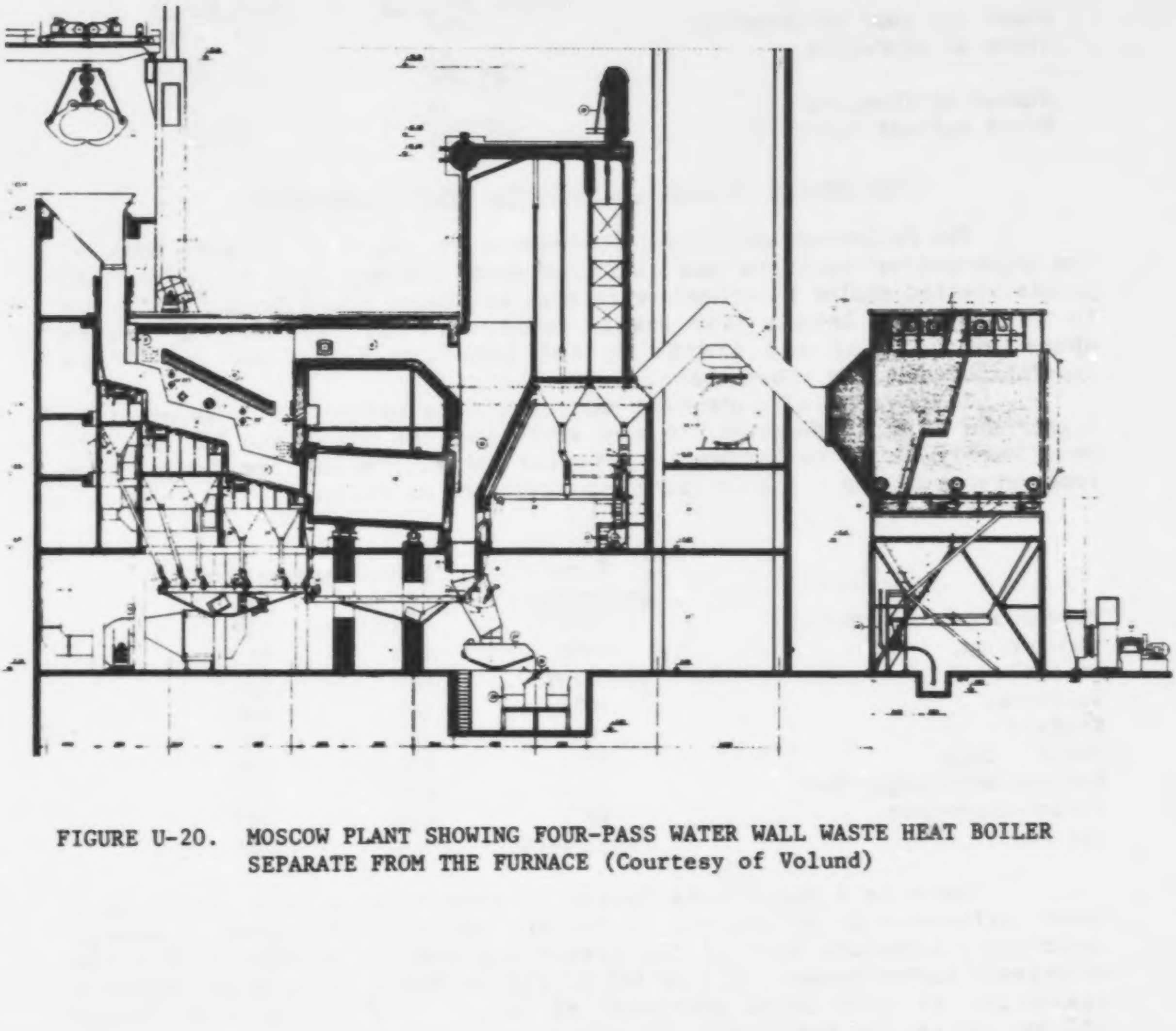


FIGURE U-20. MOSCOW PLANT SHOWING FOUR-PASS WATER WALL WASTE HEAT BOILER SEPARATE FROM THE FURNACE (Courtesy of Volund) the tubes is lower and the boiler is easier to clean. The operational availability is better and there have been longer run times.

The Volund organization is proud of the lack of corrosion in any of the four furnaces over the 7-year period.

		Units No. 1-3	Unit No. 4
Hours per year performance		6,500	6,500
Years of operation		x7	x2
	=	45,500	13,000
Number of furnaces		x3	x1
Hours without corrosion		136,500	13,000

Superheater Sections of Boilers, General Comments

The following additional discussion is required because many of the superheater sections have suffered metal wastage. Nine of the fifteen plants visited employ superheaters to heat saturated steam from the boiler to temperature levels that enable relatively efficient steam turbine operation. Six of the plants do not generate power and therefore superheated steam is unnecessary.

The degree of superheat employed is a matter of judgement: the higher the steam temperature the more efficient the plant can be, but the more likely it is to suffer superheater tube corrosion. The design steam temperatures of the 9 plants using superheat are as follows:

	Date of First Operation	Steam Temperature C	Steam Temperature F
Werdenberg-Liechtenstein	1974	395	743
Baden-Brugg	1970	400	752
Duesseldorf	1965,1972	500	932
Wuppertal	1976	350	662
Krefeld	1976	376	710
Paris - Issy	1965	410	770
Hamburg-Stellinger Moor	1972	410	770
Zurich-Hagenholz	1973	420	788
The Hague	1968,1974	425	797

There is a surprising spread in temperatures here indicating a broad difference in philosophy toward the desired efficiency of energy recovery, although most of the plants are seen to operate within the relatively narrow range: (371 to 427 C) 700 to 800 F. Achieving reliable operation at this level when burning potentially corrosive municipal refuse, calls for great care in design and operation because of the possibily chemically active nature of the flyash which inevitably coats the superheater tubes. To cope with this threat there are many different configurations of superheaters in use and a "best" design cannot yet be chosen. The development process is still under way. Nevertheless, certain preferable features of successful superheaters are emerging.

Protective Deposits

Of major importance is to design the superheater and to operate in such a way that a hard deposit of flyash always coats the tubes, because such a deposit helps to protect the tube metal from corrosive attack. The reality of this protective effect has become apparent to almost every plant operator who has sought to operate a clean boiler through over zealous use of soot blowers. On the other hand, to maintain good heat transfer the ash deposit must not be permitted to become too thick.

A protective ash coating ranging between a minimum of about 3 mm (0.120 in) and a maximum of 15 mm (0.6 in) appears to be in the desirable range. Safe methods for controlling the thickness of this ash deposit will be discussed later.

Deposit Temperature

The whole boiler and stoker design and operation are crucial in arranging to keep the protective ash deposit on the superheater tubes from becoming too hot. At some temperature, not well defined, that protective deposit can reach a level where it is no longer protective, but becomes chemically active. The mechanism by which the ash constituents will attack the tube metal is not clear, but the various theories on tube corrosion will be discussed later under corrosion. It appears that if the ash deposit never exceeds a temperature of about 1300 F (744 C) the deposit is benign and serves as a protection. In controlling the superheater tube to a safe temperature level, plant operation is extremely important because "excursions" in combustion rate can overheat an otherwise "safe" design. On the other hand, some superheaters appear much more vulnerable to the effects of temperature overruns than others, and thus some will tolerate some gas temperature fluctuations without overheating the protective ash deposits.

Example of Third Pass Superheater Location (Werdenberg - Liechtenstein)

At this stage of superheater development it appears that the most successful design places the superheater as far away as possible from the flame-filled furnace. Earlier Figure U-3 showed the boiler-furnace superheater arrangement at the Werdenberg-Liechtenstein plant. After the hot gases rise vertically out of the furnace they are required to flow through 2 vertical water-tube-walled passes before they enter the 2 banks of superheater tubes in the third pass. These banks are horizontal and located at the entrance to the bottom of the pass. As in most plants, superheat control is achieved by attemperator which injects treated feedwater into the steam as it moves from the first bank of superheater tubes to the second bank.

The gas flow pattern is straight upward through the banks as the tubes are in line and not staggered. They are spaced 100 mm (4 in) on centers in both directions. In future designs the manufacturer favors more gas space between the superheater tubes. The design temperature for the gas entering the first superheater section is 650 C. (1203 F).

A single cascade of falling steel shot for one period of 4 minutes in each hour cleans the economizer and superheater. The top row of superheater tubes is protected by steel shields from the impact of falling shot. Every 5,000 hours the economizer and superheater are washed by a German company that specializes in boiler cleaning.

The plant began operation in April 1974. In 1974-1975, the new plant was operated at an excessive rate amounting to a 20 to 29 percent overload. Formal warning to the owner by the manufacturer of the possible deleterious consequences of such overloading led to subsequent operation at more nearly normal loading.

At the time of our visit, May 2-4, 1977, there appeared to have been no permanent damage resulting from the period of overloading. However, at the end of the first 11,000 hours of operation in 1976 the first row (bottom) of horizontal superheater tubes had to be replaced because of erosion. This could very well have been a direct result of overfiring the system. The manufacturer expects that the first (bottom) row of superheater tubes may need replacement every 10,000 to 11,000 hours owing to erosion or corrosion or a combination of both. Operations at this plant has not continued long enough to reveal whether this actually is required. The fact that only the first row of tubes was affected suggests that possibly the protective deposit was mechanically eroded away by high-velocity flyash particles during the period of overloading that occurred in 1974-75.

Example of First Pass Superheater Location (Duesseldorf)

In contrast to the conservative third pass design at Werdenberg, which was made in about 1971 in preparation for construction in 1972 to 1974, a much more compact arrangement was used at the much larger Duesseldorf plant which started up in 1965 and was shown in earlier Figure U-5.

In this plant the superheater is located immediately above the furnace at the top of the first or radiation pass. Hindsight now makes clear that this superheater is more vulnerable to corrosion than the newer Werdenberg design. Another major factor encouraging more superheater corrosion at Duesseldorf is that the steam temperature is nearly 111 C (200 F) higher than at Werdenberg 500 C (932 F) versus 395 C (743 F). This high temperature is required because the steam is supplied to the adjacent Flingern municipal power plant.

The relatively close proximity of the superheater to the furnace flame in the Duesseldorf plant was a natural choice based on fossil-fuel practice. At the time these boilers were designed, 1963-64, although tube corrosion had already appeared in other waste-burning plants, the causes of that corrosion were unclear, and there was much inconclusive debate over many different theories of corrosion that had been advanced. Even today (1978) there remains considerable disagreement as to the principal causes as discussed later under corrosion. However, the relatively mild superheater corrosion at the small Werdenberg plant just described, and the so-far negligible corrosion at the larger but similar Hagenholz plant at Zurich, indicate that the remote positioning of the superheater away from the furnace flame is an essential factor in avoidance of corrosion.

Dacha Configuration

A more recent design of superheater being tried is to have the vertically suspended platens located as shown earlier in Figure W-21 in a horizontal second pass which follows the radiation pass. It is called the Dacha boiler because of its long, strung-out shape (named after the female dachshund). This superheater arrangement enables tube cleaning by means of periodic mechanical rapping instead of by the more forceful conventional steam-driven soot blowers. This again is a clear recognition of the protective value of the ash deposits on the tubes. Experience indicates that periodic rapping removes enough of the deposit to maintain acceptable heat transfer while allowing enough of the deposit to stay on the tubes so that they are protected against chloride attack. It is too early to tell whether this is effective in reducing superheater corrosion but the proponents of this design have been encouraged by trouble-free performance so far.

Superheater Protection

Although some of the concepts presented in the following quotation from Stabenow are slightly at variance with the interpretations just given regarding superheater design, in the main they constitute sound advice on the design, care and operation of superheaters.

"Many superheater problems do not arise during normal operation but are easily caused during start-up periods. The following operational guidelines should be considered to minimize start-up corrosion problems:-

Startup Situation That Leads to Unfortunate Consequences

"1. Superheater is dry until boiler water reaches 212°F.
   - a) Superheater tubes will reach gas temperature during this period which may cause tube deformation.
   - b) Overheated tube surfaces will burn-off deposits and protective coatings.
   - c) During initial start-up, unitl full furnace temperature is attained unburned volatiles containing CO, H_2O, HCL, SO_3 and other corrosive components will attack hot superheater metal surfaces.
   - d) Uncooled superheater tubes are especially vulnerable to stratified gas streams during start-up period.
   - e) Boiler waterwall tubes containing hot circulating boiler water are not subject to such corrosive attacks. (500 F)
   - f) As soon as boiling takes place in the steam drum, sudden shock-like cooling of the superheater tubes takes place and causes severe stresses in tube support attachments.
   - g) Even when using alloy steels for the superheater tubes, the problem is not

solved but the tube life is only extended for a longer period between replacements, if the following precautions are not followed.

Solution to the Startup Problem

"2. Recommendations for protection of superheater tubes during start-up period.

"Superheater tubes in incinerator boilers may be considered more vulnerable to corrosion than any other boiler section, especially if they are subject to frequent start-ups. The use of non-drainable superheaters should be avoided since venting during the warm-up period may cause difficulties due to entrapped water in some tube loops. In contrast a horizontal superheater is easily drained and vented and steam can be bled-off as soon as the boiler water reaches the boiling point.

"Due to the much slower heating-up of refuse fired boilers the superheater tubes are subjected to a much longer exposure to the rising furnace gas temperatures which represents a critical period for possible corrosive attack.

"In plants, where multiple incinerators are installed, saturated steam may be drawn from an operating boiler to keep the superheater tubes cool and free from stresses during the start-up period. Once the boiler under start-up has begun to generate its own steam, the superheater section should be vented continuously until the boiler is put into service.

"It is also important to keep a close watch on the stack temperature as gas temperatures below the dewpoint 177 C (350 F) may cause corrosion. Utilization of the start-up or auxiliary burners will assist in heating up the boiler much more rapidly thus reducing the period of exposure of possible superheater tube corrosion and consequently prolonging their life expectancy.

Recommendations for Normal Operation

"3. Effects of combustion in the furnace on superheater tubes during normal operation.

a) The life of the superheater tubes is endangered not only during the start-up period until full steam flow through the tubes has been established, but the damage can also occur during continuous operation resulting from poor combustion conditions, excessively deep refuse beds, lack of proper undergrate air distribution and insufficient overfire air penetration through the burning zones.

b) The furnace gas temperature must be reduced by radiant absorption in the primary and secondary furnaces to a point below 1400 F, before entering the superheater to prevent heavy fly-ash slag deposits which can be removed only by means of power tools during semi-annual shut-down periods. A multipass boiler design has proven to alleviate this problem to a minimum.

c) Assure uniform refuse feed rate and distribution to stoker to obtain a thin fuel bed that will ignite and burn rapidly and continuously under controlled furnace temperature conditions. Pile up of solid waste displaces the fire and causes distillation of volatiles which, if not quickly ignited, will cause severe corrosion. CO formation is the best indicator of incomplete combustion. Where CO can be measured, corrosion is apt to occur. To overcome incomplete combustion three preventive design steps must be taken:

    aa) All smoldering gases from the nearly completed combustion in the area at the rear end of the stoker must be reheated and ignited in the high temperature combustion zone for final burn-out to reduce to a minimum the occurence of traces of non-aqueous condensibles.

    bb) The violently burning solid waste mass at the front end of the stoker must receive intensive and highly penetrating, turbulent, and overfire air jet streams, preheated for rapid completion of combustion, thus eliminating the presence of any CO or other harmful corrosive constituents in the main gas stream.

    cc) As the furnace is operated under a slight negative pressure infiltration of air other than that supplied by the forced draft fan, must be eliminated. Air leakage at the feed chute section can cause heavy slag formation, while false air entry at the point of residue discharge can cause wide fluctuations in the stack gas composition and its CO_2 content thus

> resulting in combustion instability and reduced overall efficiency.
>
> "The intensity and distribution of the overfire air as previously described will greatly reduce the harmful constituents in the gas stream, reduce the fly-ash carry-over and greatly prolong the life of the superheater and boiler tubes assuring long "on-stream" availability of the steam generating incinerator during the full annual season.
>
> "Sootblowers can also be a source of trouble both in the superheater and boiler sections. Excessive sootblowing has a sandblasting effect on directly exposed tubes and may penetrate through the protective oxide coating on the tubes thus imperiling the bare metal by corrosive attack and severe pitting. For this reason alloy shields or welded studs covered with silicon carbide should be applied to the tubes at points in close proximity to the sootblower blast.
>
> "Uneven distribution caused by low gas velocities over the tube sections will result in unbalanced heating of the tubes and may cause stress corrosion primarily at tube bends".

Superheater Tube Materials

Many superheaters are made of carbon steel. However, the tube corrosion experience in most units has encouraged a trend toward low-alloy and, in some cases, high alloy steels. Table U-2 shows the superheater tube materials used in most of the plants visited.

Tube Shields

Many different forms of metal tube shields have been tried, sometimes on water-tube walls but usually on superheaters. The predominant form is a half round shape made of alloy tubing with steel clamping straps attached as shown in Figure U-21. The most common material used is Sicromal as defined in earlier Table U-1.

The shield is clamped or tack-welded to the tube. Inevitably there is a thin air space between shield and tube which can become filled with fine ash so that heat transfer is impaired. Thus the shield metal temperature is inevitably higher than the tube metal and it, thus, is subject to more rapid corrosion. However, replacement of corroded shields is much simpler than replacing tubes and can be scheduled during routine maintenance periods. At Duesseldorf the shields are replaced every 3 months. At Baden-Brugg they are replaced every 6000 hours. Others last much longer. It depends on the severity of exposure.

Sprayed silicon carbide coatings have been tried without long term satisfaction. Coatings of alloy applied by welding are being tried at Duesseldorf (See Figure U-22).

A few superheaters have been partially protected by rammed silicon carbide held in place by welded studs. This method has not been as successful as it has been in protecting wall tubes. It is much more

TABLE U-2. SUPERHEATER TUBE MATERIALS USED

Plant	Name	Year Plant Started	Material Designation(1)	Type	Composition Percent
1	Werdenberg-Liechtenstein	1974	--	--	14% Cr, 3% Mo in first section; plain carbon steel in second
2	Baden-Brugg	1970	—	—	14% Cr, 3% Mo
3	Duesseldorf(3)	1965, 1972	—	—	Units 1-4: Carbon steel with 0.25-0.35% Mo Unit 5: Carbon steel with 0.4-1.1% Mo, 0.7-2.5% Cr
4	Wuppertal	1976	35.8II	Carbon	Last 2 (highest temp.) rows are 15 Mo 31
5	Krefeld	1976	35.8I	Carbon	Same material as used in boiler convection section
6	Paris:Issy	1965	—	Carbon	
7	Hamburg:Stellinger-Moor	1972	35.8I	Carbon	
8	Zurich:Hagenholz	1973	35.8II(1a)	Carbon	Highest temperature bank is 15 Mo 3
9	The Hague	1968, 1974	--	Carbon	New unit (No. 4, 1974) uses 15 Mo 3
10	Gothenberg	1972	--	—	No superheat; some wall tubes use "sandwich" tubes(2) - stainless cover on carbon steel

(1) Tube Material Compositions:

35.8I (Similar to DIN 17175)		15 Mo 3	
C	≤ 0.17%	C	0.10-0.20%
Si	≤ 0.35	Si	0.10-0.50
Mn	≥ 0.40	Mn	0.30-0.80
P	≤ 0.050	P	≤ 0.035
S	≤ 0.050	S	≤ 0.035
Cr	< 0.030	Mo	0.45-0.65

(3) Stainless Steel Replacement at Duesseldorf (1972):

X8CrNiNb1613	
C	≤ 0.08%
Si	0.25-0.55
Mn	1.10-1.4
Cr	15-17
Ni	12-14
Nb	> 10 times C

(1a) 35.8II is similar to 35.8I but has lower content of C, Si, S and P.

(2) The "sandwich" tubes are made in Sweden by Sandviken; the stainless steel coating extruded onto carbon steel tube is 1.6 mm (0.063 in.) thick. Cost is approximately 10 times that of plain carbon steel

FIGURE U-21. HALF SHIELDS FOR CLAMPING ON SUPERHEATER LEADING FACE AT BADEN BRUGG (Battelle Photograph)

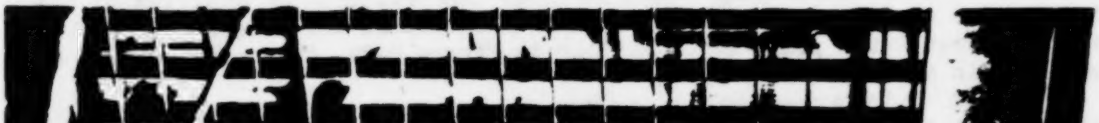


FIGURE U-22. HARD COATING ON BENDS OF SUPERHEATER TUBES TO BE INSTALLED IN THE SECOND PASS OF BOILER NO. 5 (Photograph May 17, 1977) difficult or impossible to apply in many superheaters and, if used extensively, would greatly reduce heat transfer.

Comments About Specific Superheaters

Braden-Brugg Superheater

An effective compromise between the vulnerable position of the superheater at Duesseldorf and the remote location in the Werdenberg boiler is the Baden-Brugg plant shown earlier in Figure U-24. This plant was first operated in November 1970.

In this arrangement, as the gases reach the top of the first boiler pass they are turned 180 degrees and then pass downward through the second water-tube walled pass which contains the superheater. Final steam temperature is 400 C (752 F). The superheater tubes are vertical and are suspended from the top. They are 4 m (13 ft) long, 33.7 mm (1.32 in) dia. and are spaced on 120 mm (4.7 in) centers. The superheater steel is 14 percent chromium, 3 percent molybdenum. At first they were 2.9 mm (0.11 in) thick. Later the thickness was increased to 3.2 mm. Now they are 4 mm (0.15 in) thick. The final thick walled tubes were installed in Boiler No. 1 in 1972 and in Boiler No. 2 in 1974.

Although the gas flow through the superheater is mainly parallel flow, the horizontal entry of the gases into the superheater from the first pass is actually cross flow. Thus the hot gas, at a temperature of 700 C (1292 F), carrying potentially erosive and corrosive flyash, impinges against the 23 vertical superheater tubes in the first row. Initially this caused some tube wastage and the first row of tubes was replaced in 1972 after barely a year's operation. Figure U-23 shows the longitudinal failure of a Baden-Brugg first row superheater tube. Accordingly, in October 1973, after 11,290 hours of operation in Boiler No. 1, half shields made of Sicromal 10 steel tubing (see Figure U-21) were clamped over the leading face of the first row only. This is an 18 percent chromium alloy. Thicker walled super-heater tubes have also been installed and an additional 17,810 hours had been achieved at the time of our visit on May 9, 1977. The shields must be replaced about every 6000 hours. The plant management estimates that the present superheaters will last 60,000 hrs. Again, the fact that only the first row of superheater tubes has so far been affected indicates that erosion of the protective ash coating may be exposing the tubes to corrosion.

Although steam-actuated soot blowers are available for cleaning ash deposits from the superheater tubes they are not used because of the wide-spread experience that soot blowers often accelerate tube wastage by removing the protective ash deposit. These superheaters are cleaned manually every 6 weeks, on weekends, by means of compressed air nozzles which can be inserted through the access doors in the wall of the superheater passage.

Duesseldorf

While the vulnerable position of the Duesseldorf superheaters has already been described in this section, it is instructive to follow the experience with corrosion there and the steps taken to combat it. The

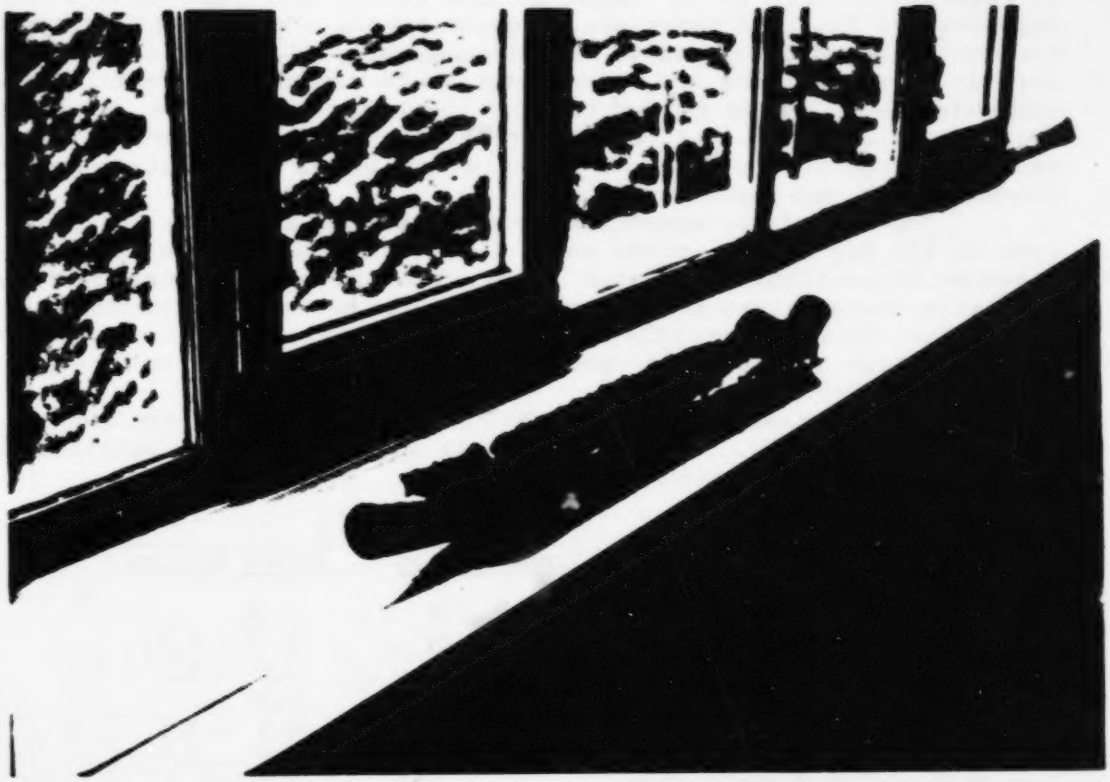


FIGURE U-23. BADEN-BRUGG RUPTURED FIRST ROW SUPERHEATER TUBE (Battelle Photograph) following covers the superheaters for Units 1-4 built in 1964 and the later Unit 5 built in 1971.

In all boilers at this plant, the high-temperature section of superheater is a suspended platen type located at the top of the first open boiler pass as shown earlier in Figure U-6. Experience at many plants has indicated that it would be desirable to position the superheater at a greater distance from the main furnace. For one thing, the gas cooling rate is relatively slow as it rises in the first open pass toward the superheater. Thus, if there are frequent bursts of high temperature gas leaving the furnace because of the inhomogeneity of the refuse causing erratic burning, there are then likely to be moments of excessive gas temperature striking the exposed bends of the suspended platens. Also, in the case of Units No. 1-4, shown earlier in Figure U-5, there is direct radiation from the furnace to the platens which may contribute to overheating any ash deposits on the platens.

The rest of the superheater sections in this plant are horizontal type at the top of the second pass. Thus, the flow of steam through the superheater sections is counter flow, with the steam first meeting partially cooled gases as they pass through the horizontal sections in the second pass. Then the partially superheated steam flows to the suspended platen section in the first pass where it meets hotter gas in a range of 700-800 C (1292-1472 F).

The superheater for Units No. 1-4 is made up of three sections. The superheater for No. 5 built in 1971 is in two sections. Material in these five units and dimensions are as follows:

Units 1-4		Unit 5	
		First Section	Second Section
Carbon:	0.12 - 0.20	0.1 - 0.18	0.15
Silicon:	0.15 - 0.35	0.15 - 0.35	0.15 - 0.5
Manganese:	0.5 - 0.7	0.4 - 0.7	0.4 - 0.6
Phosphorus:	0.04	0.04	0.04
Molybdenum:	0.25 - 0.35	0.4 - 0.5	0.9 - 1.1
Chromium:	None	0.7 - 1.0	2.0 - 2.5
Tube Diameter:	33.7 mm (1.33 in)	38 mm (1.5 in)	
	38 mm (1.5 in)	38 mm (1.5 in)	
	31.8 mm (1.25 in)	44.5 mm (1.75 in)	
Tube Spacing:	150 mm (5.9 in)	150 mm (5.9 in)	
	150 mm (5.9 in)	150 mm (5.9 in)	
	600 mm (23.6 in)	600 mm (23.6 in)	

Experiences with Superheater Corrosion. Thoemen, plant manager, has recently (1976) published* a review of corrosion: "In the time from 1970 to 1972, fireside corrosions of a considerable rate appeared on the final stage platen superheaters on Boilers No. 1-4, which are installed at the upper end of the first flue. The tube side, being directed against the gas flow, showed a rapid material wastage at a rate up to 4,5 x 10^{-6} m/h (0.00018 in/hr). At first, this corrosion was interpreted as chlorine corrosion under lack of oxygen. Gas analyses, however, showed, that in these parts of the boiler, sufficient oxygen is present at any time. Only extensive analyses of the deposits of the tubes have shown a

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*Thoemen, K.H., "Review of Fours Years of Operation with an Incinerator Boiler of the Second Generation", Proceedings ASME Conference on Present Status and Research Needs in Energy Recovery from Wastes", p 171-181 Hueston Woods, Ohio, Sept. 1976, ASME, New York, NY 10017.

chlorine-corrosion released by transformation of alkalichlorides into sulphates within the deposits. As a partial remedy, the endangered tube parts were provided with protective shields in form of flat steel. This proved to be sufficient, but as these steel bars are cooled insufficiently, an inspection and eventually a partial renewal has to be made at every shut-down of the boiler, approximately every 3 months. To cut down the maintenance costs, another tube material was sought for better resistance against this corrosion. This is an austenitic steel which has the German standard sppecification: x8CrNi Nb 1613.
Its composition is:

C = (equal or less than) 0.08 percent
Si = 0.25 - 0.55 percent
Mn = 1.10 - 1.4 percent
Cr = 15 - 17 percent
Ni = 12 - 14 percent
Nb = (more than) 10 times C.

"In 1972, platens of this material were installed. On occasion of a boiler inspection, after 16,000 hr, no substantial material wastage could be found. But lately (1976), the first failure of these platen tubes happened. The loss of material is strictly limited to the outside surface of 90° bend of the U-shaped tube. The horizontal and vertical parts of the tubes are completely unharmed. By the appearance of this damage, it can perhaps be concluded that by bending the tubes not only a reduction of the thickness of the outer wall occurs, but a structural change of the material occurs too, which makes it sensitive to corrosion. Tests about this matter are running, but not yet concluded, so that final statements cannot be made. In relation to the corrosion rate of 1970, these tubes have been a significant improvement, although no protective shields have been used on these tubes.
"Returning to the boiler which is in service since 1972, No. 5, it must be said, that similar good experience with this unit has not been achieved. Contary to the anticipated effect of a reduced susceptibility for corrosion, considerable difficulty arose with this new unit too. There occurred corrosion phenomena of kinds not known before.
"Although the corrosions of the wall tubes of the first boiler pass in No. 5 are under control, a totally different picture is presented in the superheater area. Both the final stage superheater and the convection superheater were affected by numerous attacks and damages since startup. The tube failures of the superheaters have been as follows:

- 22 failures of convection superheater tubes (See No. 4 of Figure U-6
- 13 failures of final superheater tubes (See No. 2 of Figure U-6).

"An accumulation of that kind of tube failures caused by corrosions has not been observed in former years. The final (suspended platen) superheater which is of nearly the same design and arrangement as in Boilers No. 1-4, had to be renewed in two steps in the years 1973 and 1974. The cause of this failure was a fault in the design. The 14 tubes of each platen superheater had been welded together instead of being clamped. Hereby the tubes were hindered in their expansion so that after a short operation period, they were completely twisted and no longer hung vertical at the leading edge of the tubes, not only the outward tubes were endangered, but the superheater platens presented larger surfaces to the corrosion attack. With the renewal of the first half of this superheater, the first four outer tubes of each platen were made of the same austenitic steel mentioned earlier. But after about 6,000 hours of operation, one of these tubes failed and the others showed considerable attack too. Investigations were made in order to trace the cause of this short tube life, compared to that of the same tubes in the other boilers. A new phenomenon was found not known up to that date. On the presuperheater too, being located at the upper end of the second gas pass as a convection tube bundle, corrosion occurred to an extent not known from other boilers. Not only the tube bends were affected, but at the middle section of the tube bends, the material was carried away at the top side, the material loss at the middle sections occurred at both sides of the tubes at an angle of about 30° to the vertical axis as a longfaced erosion. In addition, not only the first or second row of the tubes is affected, but the damages continued throughout the whole upper tube bundle."

Causes of the Corrosion. "By search for the possible reasons of this intensified corrosion, it was found that in 1973 about 1 year after he start of operation of Boiler No. 5 a new situation had come up in the method of operation. In May, 1973, a shredder-installation for bulky refuse (wood of any kind, furniture, boxes, crates, etc.) was started. Due to space arrangements between the shredder the boiler, most of the shredded material is fed into this unit."

Thoemen's explanation of how this caused a concentration of potassium chloride in the tube deposits is given in full in his paper.

Thoemen's conclusions regarding corrosion protection for superheaters is:

- Good mixing of refuse to avoid concentration of corrosive salts in one boiler
- Clamp protective metallic shields on tubes at vulnerable locations. He finds that a convenient alloy for this purpose because it can be formed and welded is:
  - Carbon: 0.1 percent
  - Silicon: 1.0 percent
  - Aluminum: 0.8 percent
  - Manganese: 1.0 percent
  - Chromium: 6.5 percent

  The shield lasts 3 to 12 months.
- Use alloy steels in tubes
- Plasma-gun coating by metallic or ceramic materials. This will be tried at Duesseldorf.

The earlier Figure U-22 shows a hard coating applied to the bends of superheater tubes to be installed in 1977 in the second pass of Boiler No. 5 to determine its usefulness in reducing tube wastage.

Soon after Boilers No. 1-4 began operation in 1965, a limited amount of corrosion appeared in the top tube row of the horizontal superheater sections in the second pass. However, as soon as a protective deposit developed there, corrosion almost ceased. Thoemen described this situation in 1972*:

"For the first time after about 1,000 hours of operation time, we experienced comparatively severe corrosion on the tubes of the first stage superheater at the side of the direction of gas flow. The uppermost rows of tubes of the superheater carried, under a relatively small scale of deposits, a heavy layer corrosion products. By thickness of this layer, it had to be concluded that rapid wastage of these tubes could be expected. However, as operations continued, the corrosion rate declined and has reached a level which causes a barely measurable waste of material. The tubes now are covered with a hard layer of deposits."

The importance of a protective deposit is thus emphasized. Also the deleterious effect of any action, such as excessive soot blowing, is emphasized. However, at this plant, excessive tube wastage because of soot blowing has not occurred. Mr. Thoemen emphasized the importance of the following in safe soot blowing:

- Steam lines must be well drained to avoid blasting slugs of water against the tubes. Tubes are blown once per shift.
- Protective shields are very successfully used to guard against soot blower erosion.
- Steam jet pressure must not be too high.
- A thermocouple in the steam line can be used as an operating guide. The temperature should be well above saturation temperature to avoid blowing slugs of water when the soot blower is turned on.

Wuppertal

The 4-boiler plant built by VKW at Wuppertal in 1971-75 benefitted from the experience nearby at Dusseldorf, also built by VKW. Figure U-24 showed earlier that the superheater is not a suspended platen hanging directly above the furnace, as at Duesseldorf, but consists of horizontal tubes in the second pass. When the furnace gases reach the top of the first pass they turn through 180° at moderate velocity and flow downward through the superheater sections which consist of two banks in series of horizontal tubes installed in a sinuous manner. The nine rows of tubes in the first section are formed of carbon steel designated ST. 35.8 II. The last two rows in the second section are formed of alloy steel designated 15 mo 31. This is the point of maximum steam temperature estimated at 420 C (788 F). The design final steam temperature is 350 C (662 F). The tubes are not staggered in the gas flow but are in-line with the center lines of the rows 225 mm (8.8 in) apart. The superheater is cleaned by steam blowers which initially operated at 15 bar (1500 Kpa) 218 psig . However, because of well-known experiences elsewhere with the high velocity of steam blowers having a cutting or erosive action on adjacent tubes, these blowers are now operated at a reduced pressure of 10 bar (1000 Kpa) 145 psia . Also, the tubes likely to be eroded by the steam are covered on the exposed side by 6-mm thick (0.24 in) half-round steel shields made of Sicromal. So far the shields tried of Sicromal 8 and 9 did not last long. Sicromal 10 seems to be better. The composition and properties of Sicromal were given earlier in Table U-1.

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*Thoemen, K.H., "Contribution to the Control of Corrosion Problems on Incinerators with Water-Wall Steam Generators", Proceedings 1972 National Incinerator Conference, New York, N.Y. P 310-318, ASME, New York, N.Y. 10017.

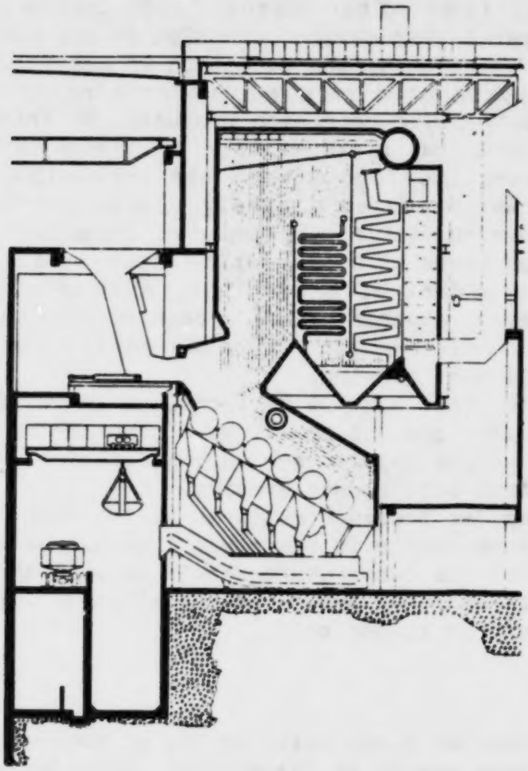

FIGURE U-24. WUPPERTAL PLANT SHOWING SUPERHEATER LOCATED IN SECOND PASS AWAY FROM FURNACE FLAME (Courtesy Vereinigte Kesselwerke).

The estimated gas temperature leaving the furnace radiation section is 830 C (1526 F). As the gas enters the superheater it has cooled to about 720 C (1328 F).

Superheat temperature control is provided by a spray-type attemperator between the two sections. Attemperators are spray chambers that inject demineralized water into the steam flow so that steam temperature can be controlled to plus and minus 5° C. Maximum steam temperature ahead of the attemperator is estimated to be 420 C (788 F).

Only 2 of the 4 Wuppertal units were being operated at a time in 1977 and it is too early to know whether the second-pass location of the superheater was beneficial in elimination of corrosion.

The plant operator is experienced and well aware of the importance of moderate, controlled burning in avoiding maintenance problems. Hence this plant premises to develop a record of minimal tube corrosion.

Krefeld

The new plant built by VKW at Krefeld, also near Duesseldorf, is very similar to the Wuppertal plant just described except that sewage sludge is dried and burned in suspension above the refuse. The energy taken up in drying is not available for much steam generation and for superheating. Hence the superheater is smaller. Superheat temperature is 376 C (710 F). The superheater location in the second pass is the same as at Wuppertal.

The superheater consists of 50 tubes, 51 mm (2.0 in) diameter with a wall thickness of 3.6 mm (0.14 in) and formed of 35.8 I steel. The composition of 35.8 I steel is as follows:

C	0.17 percent	P	0.050
Si	0.35	S	0.050
Mn	0.40	Cr	0.030

In West Germany this steel is identified under Standard No. 1.0305.

The gas temperature entering the superheater is estimated to be 700 to 750 C (1292 to 1382 F). There is one steam soot blower.

Not enough operation has yet occurred at Krefeld to enable assessment of reliability of the superheater design. However its performance should be similar to the nearly identical Wuppertal superheaters. The possible exception would be a beneficial effect at Krefeld of the sulfur from the sewage sludge helping to prevent chloride attack.

Paris-Issy

Considering that this plant began operation in February 1965 when superheater corrosion was poorly understood, the remote location of the vertically suspended tubes in the third boiler pass indicates remarkably astute design. Figure U-8 shows a cross section of one of the 4 Issy steam generators. There are 2 large water-tube-walled boiler passes ahead of the superheater. Apparently the main body of the superheaters has escaped corrosion. But high velocity erosion of the lower tip of the platens which face the gas flow has occurred until the tubes were rearranged to allow lower velocities.

The superheater tubes are suspended vertically in the third pass. The original superheater tubes were 38 mm (1.5 in) in diameter. The original design had 56 rows of tubes.

Operation of the units at 17 to 20 tonnes (19 to 22 tons) per hour instead of the rated 15 tonnes (16.5 tons) per hour overloaded the superheater tubes with deposits. With less cross-sectional area for gas travel, the gas velocity was three times faster than design.

The ash buildup on the superheater tubes forced much gas to the outside along the wall. Naturally the lwoer corner of the far superheater suffered from the very high velocity and high particulate loading. Baffles, to better distribute the gas flow, were one of several solutions implemented after flow model studies were completed.

Shields for Bottoms of Superheater Tubes. A new tube shield designed was tried from 1967 to 1971. The two portions of Figure U-25 depict the shield arrangement.

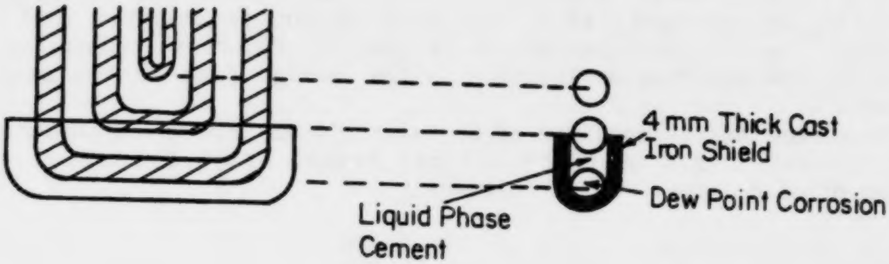

FIGURE U-25. ISSY SHIELDS FOR BOTTOMS OF SUPERHEATER TUBES

The shields, made of cast iron, cover vertically the lower one and one-half tubes as shown. The cast iron shields were 4 mm (0.16 in) thick. The void was packed with a Narcoset (North American Refractories) liquid phase filler cement.

This new shielding was supposed to protect the superheater tubes for 4 to 5 years. However, superheater tubes began failing after 2 years or 11,000 hours. In an unusual manner the failure was attributed to the steam soot blowers--not from erosion or regular corrosion but from condensation. The steam would condense and absorb into the Narcoset packing. Thus at times the wet packing would corrode the metal tube. When the above effect was analyzed, the shields were discontinued. But metal wastage by erosion continued.

Stage 3. (New Superheater with Wide Passes). The basic overloading apparently could not be relieved. Finally in 1973, a new superheater was installed which has given better service. Normal slag deposits were later removed. The 56 rows of superheater tubes were replaced by 31 rows. The tube diameter was increased from 38 mm (1.5 in) to 44.5 mm (1.77 in). The old tubes were spaced as shown in Figure U-26, as compared with the new spacing.

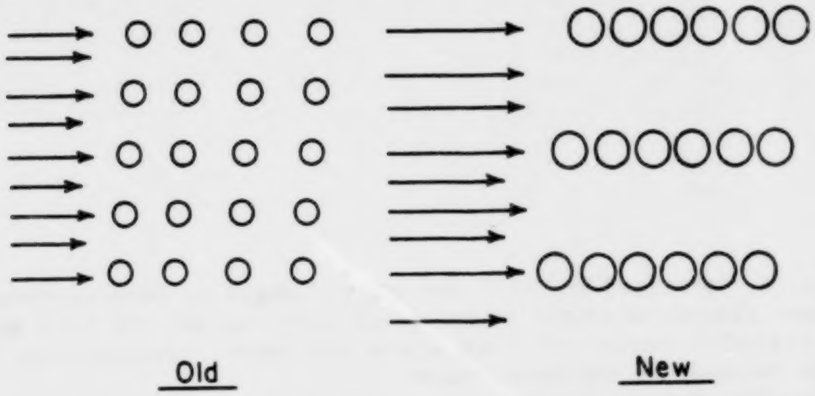

FIGURE U-26. ISSY OLD AND NEW SUPERHEATER SPACING

Stage 4. Manual Cleaning of Superheaters. With the wider spacing between tubes, Issy has adopted manual cleaning of superheater tubes with scrapers. So as to avoid erosion of the surface deposit and of the tubes by soot blowers.

All of these measures have been helpful and although tube wastage continues this new superheater had run 23,000 hours at the time of our visit.

It is of particular interest that the water-filled screen tubes at the entrance to the bottom of the third pass have not suffered extensive corrosion while nearby the bends on the bottom of the vertically suspended superheaters have required shielding to reduce corrosion.

Zurich-Hagenholz

Earlier Figure U-11 showed the superheater located in the Third Pass of Unit No. 3 at Zurich-Hagenholz. Four horizontal tube bundles are connected as shown on the following, Figure U-27.

There is a significant difference in tube configuration between Martin's earlier Paris: Issy plant (1965) and their newer Zurich: Hagenholz Unit No. 3 (1973). In Paris, the platens of superheater tubes were hung as shown below, vertically in a "harp" design. (Also see earlier Figure U-8).

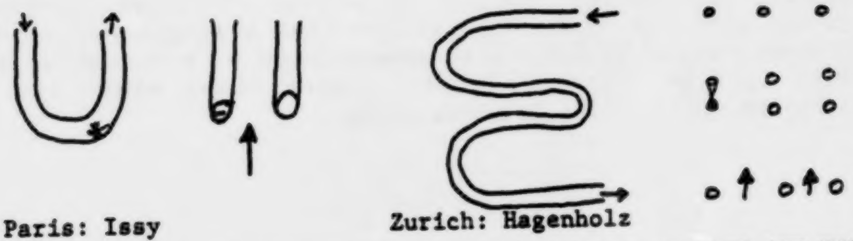

FIGURE U-27. SUPERHEATER TUBE ARRANGEMENTS AT ISSY AND HAGENHOLZ

The Paris design, (designed in 1961) was later thought to develop droplets. This would cause alternate rapid heating and cooling of the tube metal. Proper heat transfer could not take place and metal temperatures would reach the high-temperature corrosion range.

At Zurich: Hagenholz, however, (designed in 1971) the steam flow is always downward such that nothing can become trapped. Heat transfer is thus thought to be uniform and corrosion should be reduced.

The lower and hotter bundles are made from 15 Mo 3 low alloy steel while the upper and cooler bundles are made from 35.8 II carbon steel. The tube diameter is 31.8 mm (1.25 in) while the thickness is 4 mm (0.158 in). The horizontal centerline spacing is 150 mm (6 in) and the vertical spacing within a bundle is 50 and 100 mm (2 and 4 in).

The lower hottest first bundle has a maximum flue gas velocity of 6.65 m/sec (21.8 feet/sec) and average velocity slightly less at 6.45 m/sec (21.2 feet/sec). The top three bundles, however, have a slower velocity at a maximum of 6.25 m/sec (20.5 feet/sec) and an average velocity slightly less at 5.75 m/sec (18.9 ft/sec).

To better control boiler exit steam temperatue (plus and minus 5° C), an attemperator injects varying amounts of deionized, deaerated, and demineralized water. The injected water is very pure to avoid scale build-up inside the superheater tubes. The point of injecting is shown in Figure U-28 as being between the lowest and the next bundle.

About 38,200 kg/hr (84,000 pounds/hour) of steam at 38 bar (551 psi) (3800 kPa) are produced. Note that the steam enters the superheater at 260 C (500 F) and then exits with a temperature of 420-427 C (788 to 800 F) at the very bottom of the third pass. In a later design for Yokohama, Japan, Martin tried a slightly different configuration as shown in Figure U-29. In this design, the hottest tubes are the upper row of tubes in the first bundle. The Yokohama design was probably motivated by the excessively high percentage of total plastics, being 10 to 15 percent of the refuse input.

The advantage of the Yokohama design is that a slightly cooler temperature flue gas hits the hottest steam tube. Thus, the metal and tube deposit temperature is less and there will be less corrosion. Zurich, Yokohama, and Martin officials apparently believe that a slight reduction in exit steam temperature is more than compensated by a reduction in superheater metal wastage. Hence, the new Josefstrasse plant under construction in Zurich will use the Yokohama design.

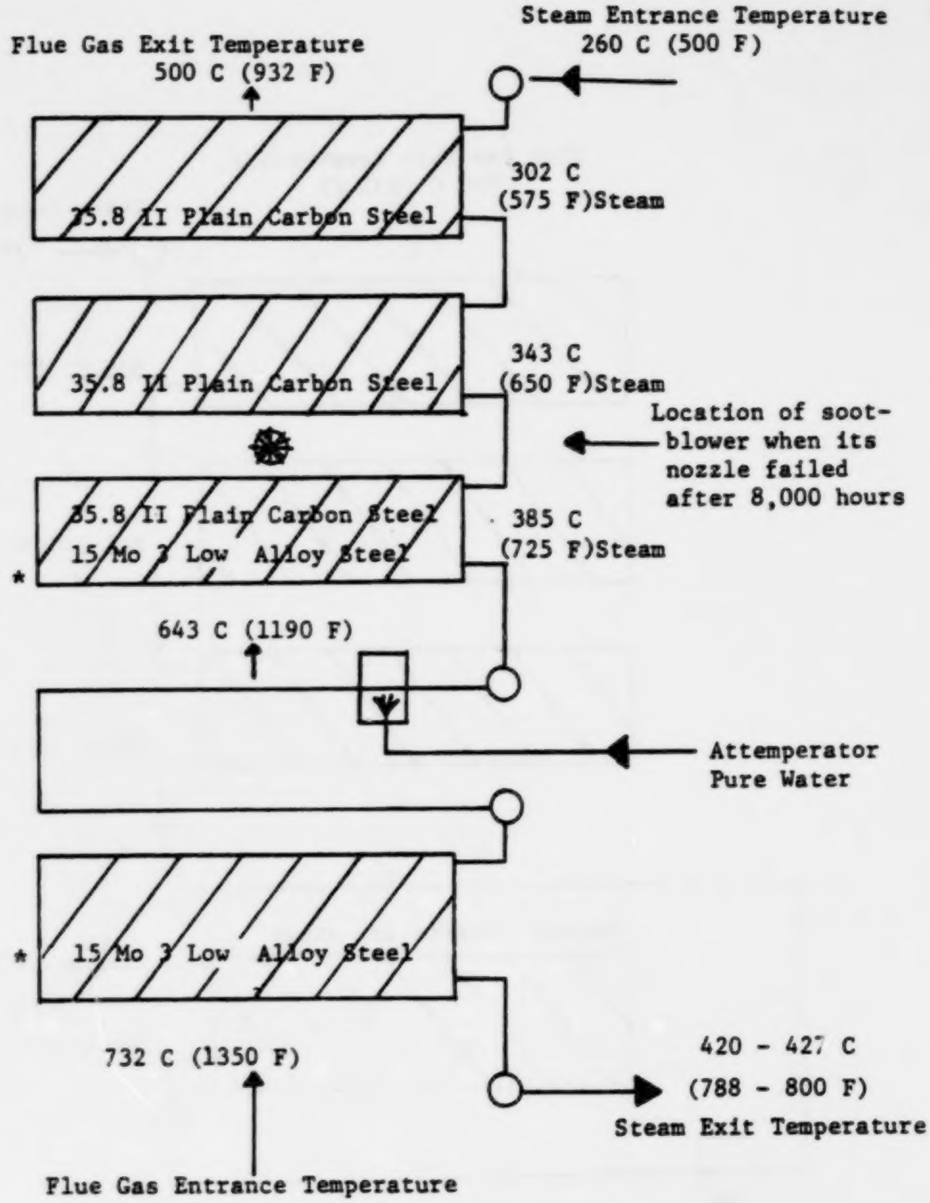
Steam Entrance Temperature
260 C (500 F)
Flue Gas Exit Temperature
500 C (932 F)
35.8 II Plain Carbon Steel
302 C
(575 F)Steam
35.8 II Plain Carbon Steel
343 C
(650 F)Steam
Location of soot-blower when its nozzle failed after 8,000 hours
35.8 II Plain Carbon Steel
15 Mo 3 Low Alloy Steel
*
385 C
(725 F)Steam
643 C (1190 F)
Attemperator
Pure Water
*
15 Mo 3 Low Alloy Steel
732 C (1350 F)
420 - 427 C
(788 - 800 F)
Steam Exit Temperature
Flue Gas Entrance Temperature

FIGURE U-28. SUPERHEATER FLUE GAS AND STEAM TEMPERATURE AND FLOW PATTERNS AT ZURICH: HAGENHOLZ

* The last and lowest loop of the 3rd bundle and the entire 4th bundle are made with 15 Mo 3 low alloy steel.

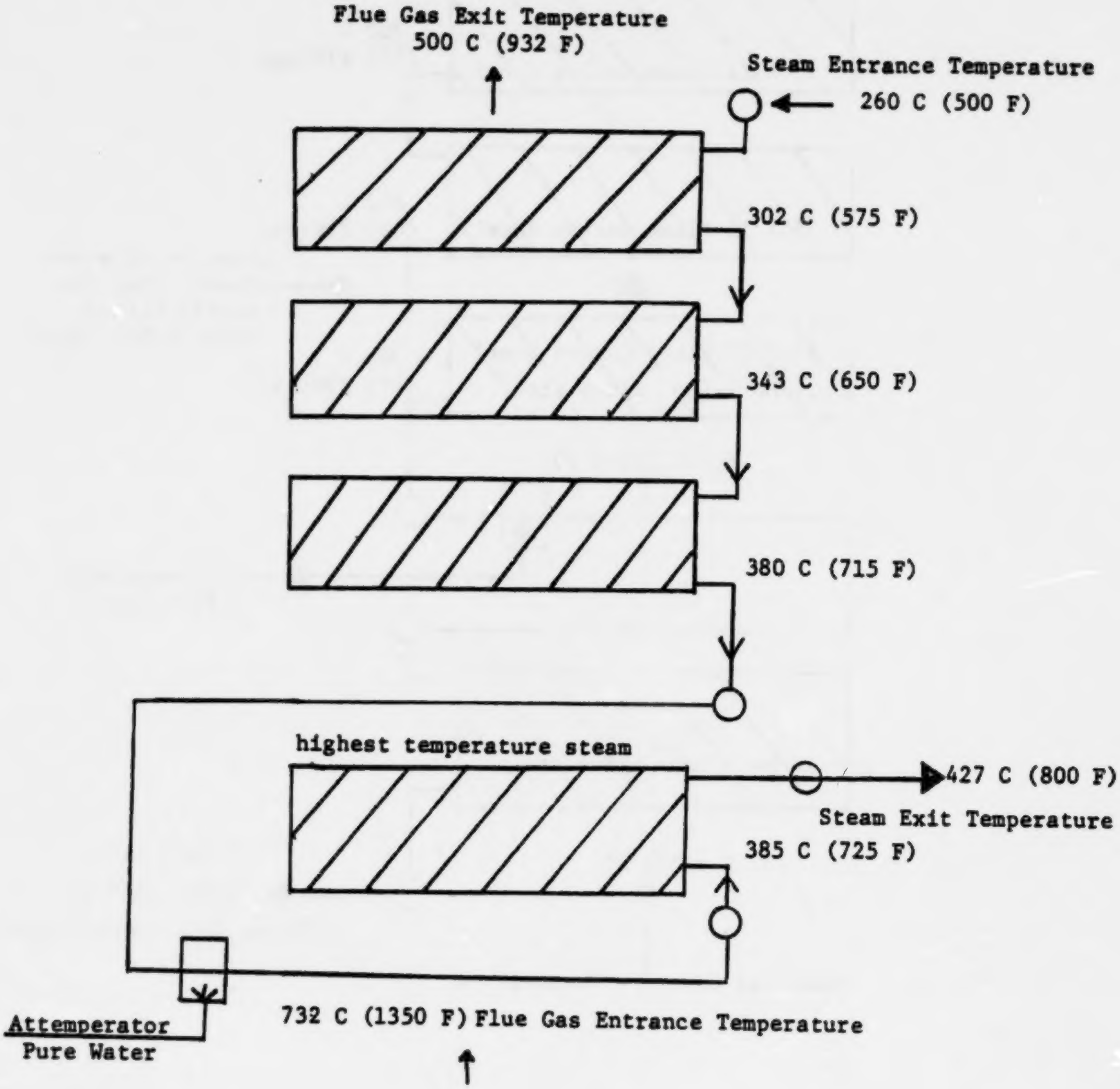
Flue Gas Exit Temperature
500 C (932 F)
Steam Entrance Temperature
260 C (500 F)
302 C (575 F)
343 C (650 F)
380 C (715 F)
highest temperature steam
427 C (800 F)
Steam Exit Temperature
385 C (725 F)
Attemperator
Pure Water
732 C (1350 F) Flue Gas Entrance Temperature

FIGURE U-29. SUPERHEATER FLUE GAS AND STEAM TEMPERATURE AND FLOW PATTERNS AT THE NEW ZURICH: JOSEFSTRASSE PLANT

Air Soot Blowers. As mentioned previously, there has (with one sootblower incident exception) been virtually no corrosion of superheater tubes in 30,000 hours. At 30,000 hours, metal wastage was determined to be only 0.3 mm (0.012 in) at many points around the tubes. In part this results from the use of air in the soot blowers.

The one exception ocurred after only 8,000 hours. A nozzle on a fixed position, rotary sootblower fell off. As a result, high pressure compressed air blew directly onto the tube sides. The nozzle failure was detected and the tubes were inspected. None of the superheater tubes failed but they had sufficient metal wastage to motivate replacement. Thus, after 8,000 hours, twenty (20) tube sections, averaging 5 m (16.4 feet) per tube each, were replaced. There have been no sootblower problems since.

The compressed air sootblowers are used daily. The two air compressors supply a 1500 m^3 (52,900 ft^3) air tank with air at a 30 bar (3000 kPa) 450 psig . The air released at the sootblower nozzle is at 15 bar (1550 Kpa) 225 psig . Officials expressed their preference for superheater sootblowing with compressed air over steam even though the air compressor costs about SF 250,000. As an official stated, "We use air for sootblowing. If we used 10 tonnes steam per hour for sootblowing, we wouldn't be able to sell it." Evidently selling the electricity required for driving the air compressors is considered less important at this plant than selling steam for district heating.

Once or twice per year, each Hagenholz boiler is manually cleaned by the Hutte Company of Recklinghausen, West Germany (near Essen). Four or 5 men spend 7 or 8 days cleaning one boiler. An alkali chemical is used. Sandblasting may be used for selected, hard to dissolve, deposits. The procedure is basically as follows for most deposit areas:

1. Spray alkali (soak, low pressure spray)
2. Rinse with water
3. Spray alkali (second soak)
4. Rinse with water
5. Scrub with brushes and other tools
6. Sandblast difficult deposits

Cleaning all the tubes (walls and bundles) in all four passes normally costs about 25,000 SF ($10,000). The dirty water coming out at the boiler bottom has a pH of about 2 so lime must be added.

Plant staff have been experimenting with an "unbalanced compressed air vibrator" for cleaning the superheater. Every two minutes, the upper three bundles are vibrated. Every second or third months, they perform a variation and interrupt the procedure for a half day.

At the older Borsigstrasse plant at Hamburg, the bundle wall anchors are hit with a sledge hammer once per week.

Convection Section. Because of extensive use of water-tube walls in all 3 boiler passes, Hagenholz Unit No. 3 does not have a regular boiler convection section. From the superheater, the gases pass to the five-bank economizer.

Hamburg-Stellinger Moor

The Stellinger-Moor plant started up in 1972 utilizes vertically suspended superheater platens in the second pass as shown in Figure U-10. Thus the flame is usually completed before the gases reach to the top of the first pass and turn to enter the superheater horizontally. If the plant did not have to burn so much higher heat value refuse than what it was designed for, or if the firing rate could be moderated, this relatively exposed position of superheater might not be subject to unusual corrosion. However, the boiler manufacturer, Walther and Company, probably anticipated some corrosion because the superheaters were installed originally with angle iron shields protecting the front row of tubes.

Figure U-30 shows the detailed arrangement of the 3 superheater bundles.

Stage 1 (Original Construction). The plain carbon steel (ST 35.8) tube used in the superheaters is 33.7 mm (1.33 inches) in diameter and 4 mm (0.16 inches) thick. The design provides a heating surface area of 470 m^2 (5057 ft^2). Retractable sootblowers are used for cleaning deposits off the tubes. Sootblowing has caused a fair amount of corrosion damage and has motivated the following stages of improvement. Corrosion problems have developed despite the Walther Company's originally shielded superheater tubes.

Stage 2 (Adding Angle Iron). When the leading superheater row began failing, despite the Walther shields, angle iron was welded to the first row of tubes. This had the intended effect of protecting the first row of tubes. However, the angle iron had the very damaging effect of concentrating the flue gas as it was directed to the sides of second and third row tubes as shown in Figure U-31.

Because of the Bernoulli effect, some gases were redirected away from going straight down the open channel and instead have nonsymetrically hit the front and one side of the tubes in the second and third rows. The angle iron had a directing or aiming effect. Accordingly, this form of shielding has been discontinued.

Stage 3 (Switch to Pressure Bent Pipes). Originally the pipes were simply "stretch" bent. Unfortunately this form of bending gathers the material on the inside curve, while thinning it out on the outside curve. Thus, the front of the bottom loops, with less original thickness, would wear out first.

Now, pressure bent pipes are installed as replacements. The Walther Company can provide greater detail.

Stage 4 (Welded Curved Shields). Two factors continued to cause corrosion. First, the retractable sootblower would remove deposits very efficiently and thus enhance the rate of exposed metal wastage. The other factor was continued erosion by the flyash in the flue gases.

To combat these problems, in April 1977, a series of 50 mm (2 inch) curved shields were welded next to each other along the front surface of the first row of superheater tubes as seen in the several portions of Figure U-32. Note the 135° angle. Sicromal 10 is the high temperature alloy

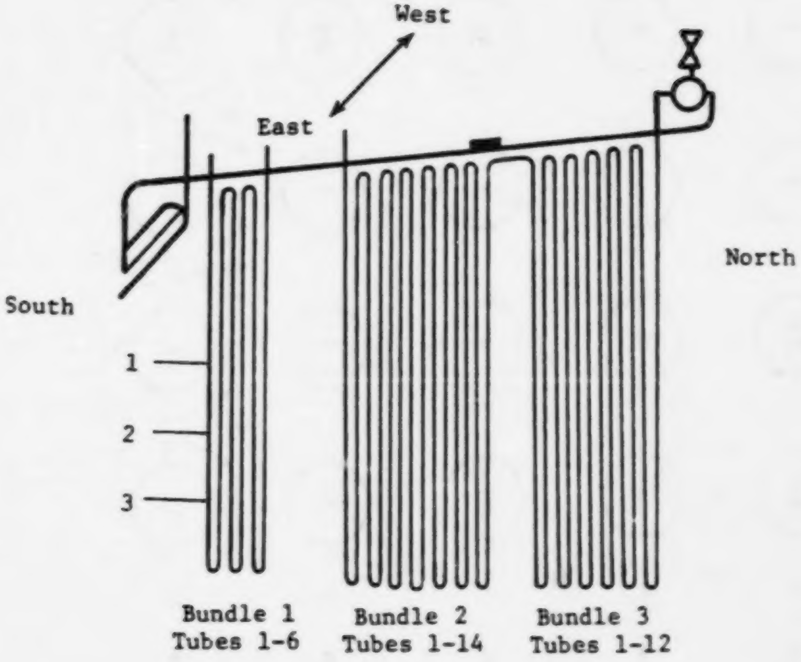
West
East
South
North
1
2
3
Bundle 1
Tubes 1-6
Bundle 2
Tubes 1-14
Bundle 3
Tubes 1-12

FIGURE U-30. THREE SUPERHEATER BUNDLES AT HAMBURG: STELLINGER-MOOR

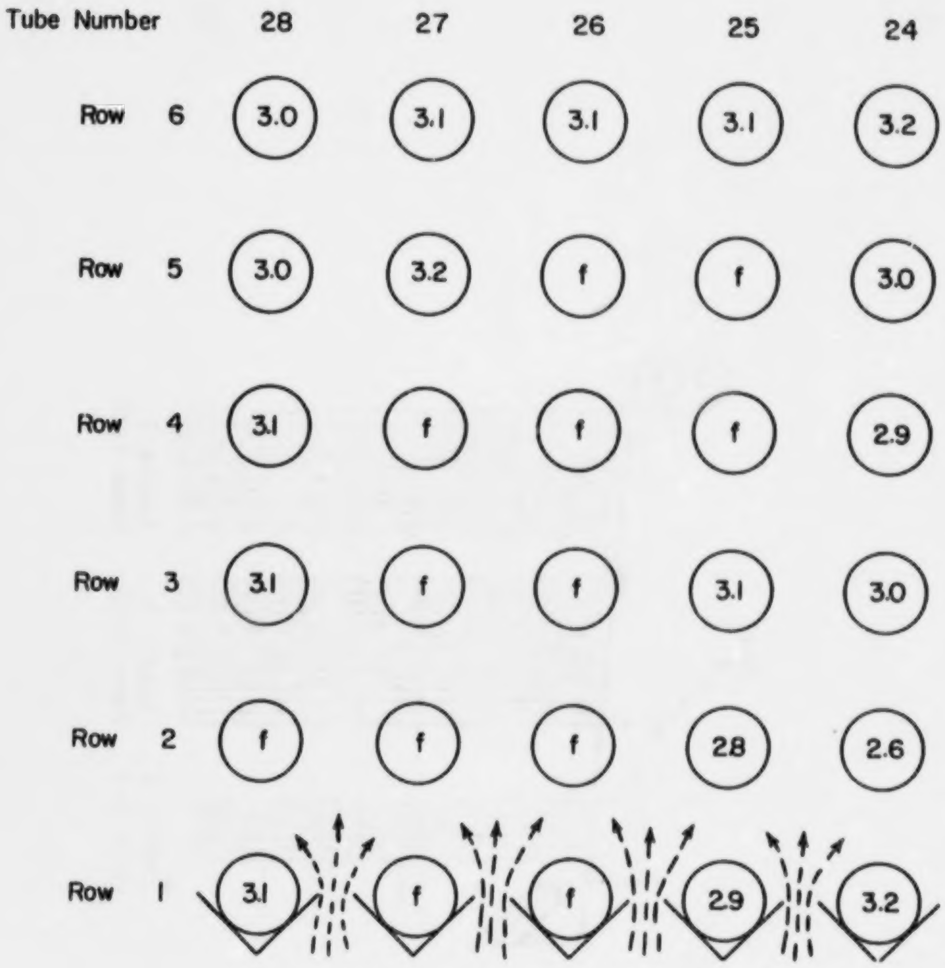
Tube Number
28
27
26
25
24
Row 6
3.0
3.1
3.1
3.1
3.2
Row 5
3.0
3.2
f
f
3.0
Row 4
3.1
f
f
f
2.9
Row 3
3.1
f
f
3.1
3.0
Row 2
f
f
f
2.8
2.6
Row 1
3.1
f
f
2.9
3.2

FIGURE U-31. FLOW DEFLECTION CAUSED BY ANGLE IRON SHIELDS ON FIRST ROW OF SUPERHEATER TUBES

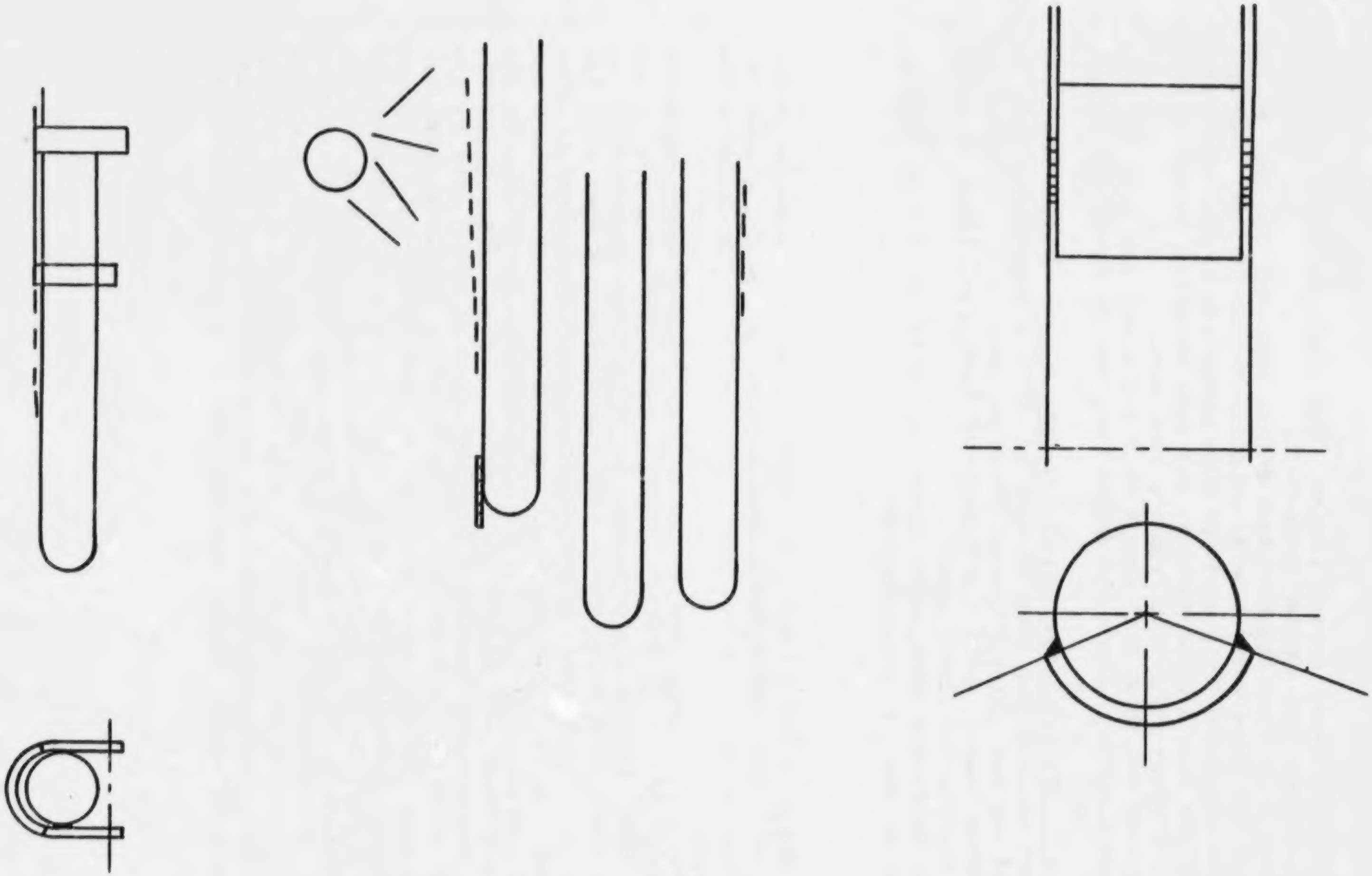

FIGURE U-32. MEHTOD OF WELDING CURVED 50 mm SHIELDS ON FIRST ROW OF SUPERHEATER TUBES material used for these curved plates. This steel contains silicon, chromium, and aluminum (See earlier Table U-1).

Perhaps 1 or 2 mm separate each shield. Note that the last shield at the bottom of the superheater tube is extended further straight down and thus away from the tube. This provides some protection of the very bottom of the tube. At the tube's upper section, the same material is not welded but formed in a U shape and bolted from the back side.

Experience has shown that when a weld fails and the tube bursts, it is more economical to replace the entire tube than to repair the damaged area.

Stage 5 (Superheater Repair Observation). While Battelle researchers were visiting the plant on June 13, 1977, a superheater tube in Boiler 2 failed and was losing 5 tons of steam per hour.

Repairmen removed about 1 m (3 feet) of four other tubes in order to get to and replace the failed tube.

After performing hydrostatic tests, the boiler was put in service, having been out of service almost two days.

The Hague

The Hague plant started in 1968, is another example of the influence of fossil fuel design habits; one vertical superheater platen was supended at the top of the first pass, very similar to the design of the Duesseldorf plant.

Figure U-13 showed earlier the original superheater and boiler arrangement for Units 1-3, as designed in 1965. The superheater was in two sections The first section was a platen-type radiant superheater which was inserted about 3.6 m (11.8 ft) downward from the water-cooled roof into the radiation chamber (first pass). As subsequent experience has shown at other plants, this was a particularly vulnerable location for a superheater. The designer estimated that the flue gas temperature, as it rose in the radiation chamber toward the superheater, would be about 955 C (1751 F). With a steam temperature leaving the superheater of 425 C (797 F) the temperature of potentially corrosive chloride salts on the superheater surface could thus rise well over 500 C (932 F) both from contact by surges of high temperature flame and from intense radiation from the incandescent gases in the furnace below. Thus, in hindsight, it not surprising that the pendant superheaters in Units 1-3 showed tube wastage within the first year of operation. The solution to this attack was to shorten the platen by about 70 cm (2.3 ft) and to increase the tube thickness from 2.9 to 5 mm (0.12 to 0.2 in). After about five years and about 25,000 to 30,000 hours operation, the pendant superheater was replaced at a cost of 60,000 Gl. ($24,600).

The second superheater section, a sinuous convection type, is shown in detail in Figure U-33 at the top of the second pass. A spray-type desuperheater (attemperator) is located between the sections. The designer estimated that the gases entering the second superheater section would be about 900 C (1652 F) and leaving it would be 807 C (1485 F). In this section, corrosion was observed two or three years after startup. However, the steam temperature there is lower and the corrosion rate is apparently not rapid. This superheater section will also soon be replaced after about 10 years service.

Superheater (Unit 4). During the three years between 1968, when Units 1-3 started up, and 1971, when Unit 4 was ordered, much had been learned both at this plant and elsewhere about some of the causes of superheater corrosion. One emerging lesson was that the superheater should be as far removed as possible from the furnace flames. In this way any potentially corrosive chloride depoosits on the tubes would not be overheated by sudden surges of flames extending far above the furnace. Also, the deposits would not be heated by intense radiation from the furnace.

Accordingly, as seen in Figure U-34, the horizontal superheater sections in Unit 4 are far removed from the furnace. Also, the entirely open second pass, completely water-tube walled, provides cooling of the gases before they reach the first superheater section at the bottom, beginning, of the third pass. Thus, instead of an estimated gas temperature of 955 C (1751 F) approaching the pendant superheater in Units 1-3, in Unit 4 the partially cooled gas entering the horizontal superheater bundle is estimated to range from 530 to 630 C (986 F to 1166 F).

Another improvement helping to alleviate corrosive conditions was to add secondary air jets in the sidewalls in Units 1-3 and to include them in the initial design for Unit 4. These jets are located high in the refractory sidewalls of the furnace, just below the coated water-tube wall of the first (radiant) pass. They help to complete the burning quickly and allow somewhat more time for the gas to cool as it moves through the passes.

The steam flow through the first (bottom) superheater section is counter flow so that the hottest steam (425 C) 797 F "meets" the hottest gas. In the second superheater section of Unit 4 the steam and gas flows are cocurrent.

The boiler redesign and air jets are just described have eliminated superheater corrosion in Unit 4 except for some wastage in the vicinity of the soot blowers. This is being satisfactorily controlled by means of carbon steel shields covering the affected tubes. It is estimated that the shields will need replacement every four years.

In Unit 4 the superheater tubes are made of 15 Mo 3 low alloy steel, 38 mm (1.5 in) diameter and 3.6 mm (0.14 in) thick. The spacing between the inline rows is 150 mm (5.9 in). In Units 1-3 this spacing was only 80 mm (3.1 in). With this wider spacing, it is estimated that the unit could run 8000 hours (nearly two years) before chemical cleaning of the tube deposits would be necessary. However, tube thickness is checked once per year, hence cleaning is needed each year before the thickness measurements are made.

At first in Unit 4 the soot blowers were operated once per shift. This caused tube erosion; hence the 20 bar (290 psia) blowers are no longer

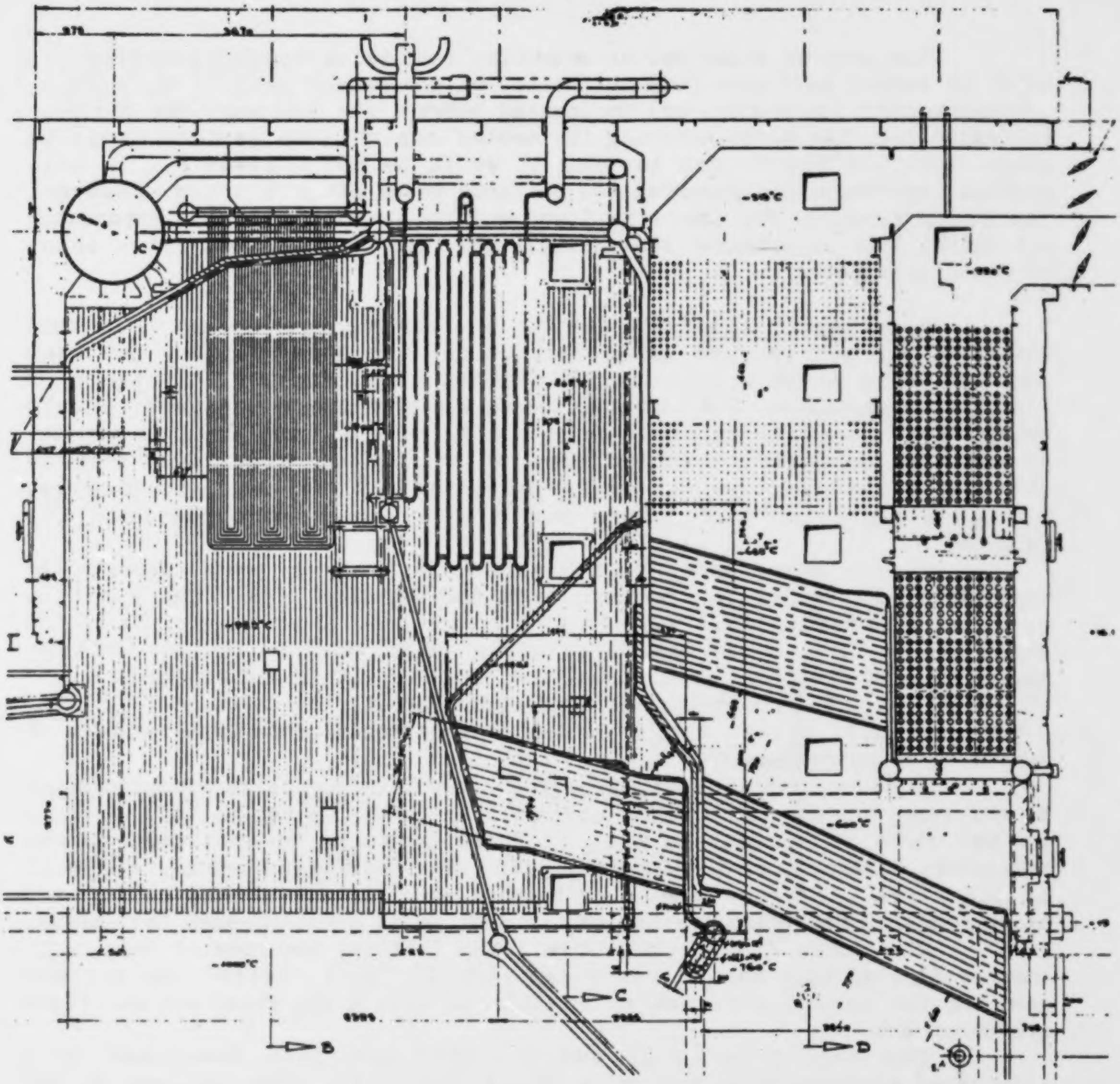

FIGURE U-33. WATER-TUBE WALL PORTION OF BOILERS IN UNITS 1-3, THE HAGUE, SHOWING SUSPENDED PLATTEN-TYPE SUPERHEATER AT TOP OF RADIATION PASS, SCREEN TUBES AT OUTLET FROM RADIATION PASS, SINUOUS TUBE CONVECTION-TYPE SUPERHEATER AT TOP OF SECOND WATER-TUBE WALLED PASS, BOILER CONVECTION SECTIONS, ECONOMIZER, AND TUBULAR AIR HEATERS. (Courtesy of Von Roll)

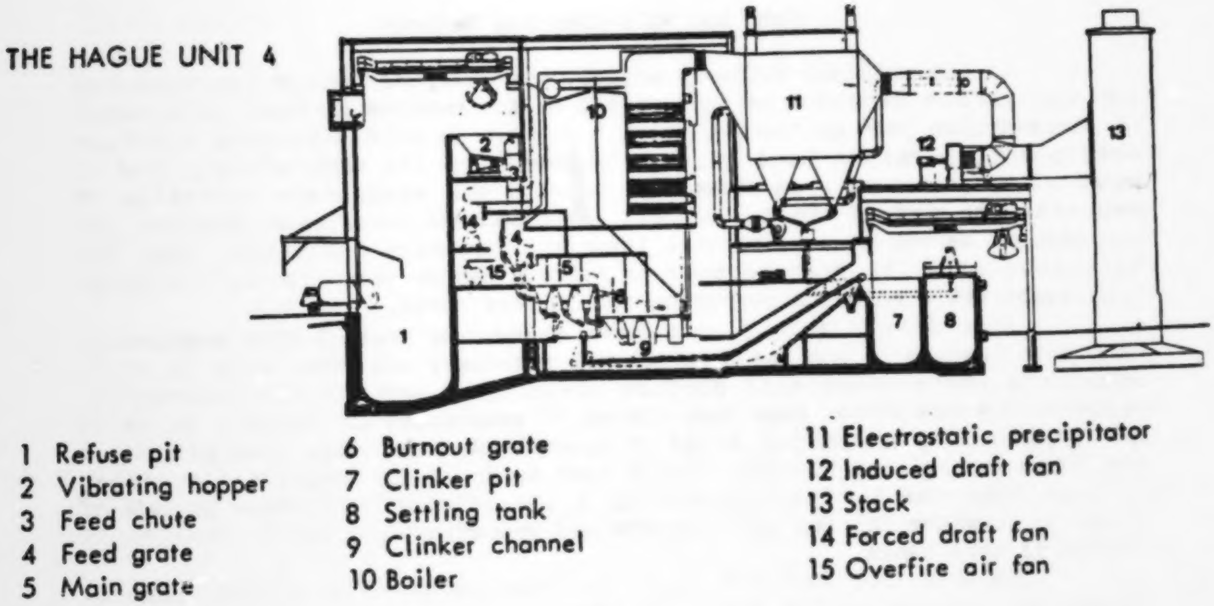
THE HAGUE UNIT 4
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
1 Refuse pit
2 Vibrating hopper
3 Feed chute
4 Feed grate
5 Main grate
6 Burnout grate
7 Clinker pit
8 Settling tank
9 Clinker channel
10 Boiler
11 Electrostatic precipitator
12 Induced draft fan
13 Stack
14 Forced draft fan
15 Overfire air fan

FIGURE U-34. CROSS-SECTION OF THE NO. 4 BOILER-FURNACE SYSTEM AT THE HAGUE PLANT. UNIT 4 WAS DESIGNED IN 1971. (Courtesy of Gemeentelijk Energiebedrijk Vuilverbrainding) [Wastenburning Energy Utility] used. Instead, the entire boiler system is cleaned aobut every three months by a Dutch contractor: FA Conservator of Rotterdam. They use high pressure jets of a solution of sodium carbonate to clean the ash deposits from the tubes.

Plants Without Superheaters

As described earlier in this section, six of the visited plants have no superheaters. High temperature steam for electrical production on industrial processes is not needed from these plants. Instead hot water or low temperature steam is used for district heating for sludge drying.

Tube and Wall-Cleaning Methods

In conventional boiler practice, the accepted method for removing ash and carbon deposits periodically from the heating surfaces is by means of steam-driven jets or "soot-blowers." However in refuse-burning practice most plant operators have quickly learned that the high-velocity jets of water slugs and steam from steam soot blowers can accelerate corrosion by removing too much of the ash deposit. As discussed under metal wastage, the ash deposit serves as a protective layer and corrosion inhibitor. When the bare tube metal is exposed once or twice a day by excessive soot blowing, high temperature chloride corrosion can be very rapid.

Accordingly some plants have abandoned soot-blowing completely. Many have learned to use the soot blowers sparingly and then only in those locations where occasional surface cleaning is particularly important to satisfactory operation. Some have turned to compressed air blowers to avoid any possibility of having slugs of steam-condensate being blasted against the tubes during soot blowing. Others have arranged the convection surfaces so that they can be shot-cleaned by a periodic or continuous cascade of steel or aluminum falling shot. Others use mechanical rapping of vertically suspended tube banks.

Tables U-3 and U-4 list the various furnace-boiler cleaning techniques employed at the plants visited.

Werdenberg-Leichtenstein

The economizer and superheater at Werdenberg are shot cleaned. Cleaning is achieved by the gravity fall of a shower of steel shot about 3 mm (0.120 in) dia which intermittently is delivered to a distributor at the top of the economizer from which it falls by gravity through the gas passages in the economizer and in the superheater. The falling steel shot cleans deposited ash from the tubes and carries it down to an ash separation system where it is removed from the shot and is transported to be mixed in with the grate residue. The cleaned shot is then conveyed pneumatically to the top of the economizer to repeat the cycle. The shot cleaning process operates about 4 minutes every hour. Some systems use aluminum shot.

The manufacturer feels that the trend will be toward vertical configuration in superheater and convection section with periodic rapping of the tubes to remove ash deposits. To minimize danger of tube metal atigue from repeated flexing the amplitude of rapping should be manual 0.5

TABLE U-3. DATA REGARDING CLEANING OF HEAT-TRANSFER SURFACES
IN VISITED REFUSE-FIRED STEAM AND HOT-WATER GENERATORS

Plant	Original Cleaning Method				Supplemental Methods		Revised Cleaning Methods				Washing		Tube Protection Opposite Soot Blowers	Comments
	Soot Blowers	Blowing Frequency	Steam bar	Pressure psig			Number of Soot Blowers	Blowing Frequency	Steam bar	Pressure psig	Type	Frequency		
Werdenberg	None	-	-	-	Shot	4min/hr	None	None	-	-	None	-	None	Mfg. favors rapping
Baden-Brugg	Steam	None	-	-	Hand	Every 6 weeks	None	None	-	-	None	-	None	Soot blowers not used because of danger to tubes
Duesseldorf	Steam	-	-	-	-	-	-	-	-	-	High Pr. water	2000 hrs, #1-4 5000 hrs, #5	Alloy Steel	Soot blower caused wastage only in economizer
Wuppertal	Steam	-	15	233	-	-	-	-	10	60	Discontinued		6mm Sicromal	Water threatened refractories
Krefeld	Only 1 steam blower	-	-	-	-	-	-	-	-	-	None	-	None	Co-firing system
Paris:Issy-les-M.	Steam	-	-	-	Steel shot in economizer	-	Discontinued, suphtr. cleaned manually				None	-	None	-
Zurich:Hagenholz	Air	-	Air 15	240	Steel shot in economizer	-	-	-	-	-	Alkali	4000 hrs	None	Experimenting with suphtr. vibrator
Hamburg:S.-Moor	Steam	1/shift	18	260	-	-	-	1/3rd shift	14-16	300-230	None	-	Sicromal 10	-
The Hague	Steam	1/shift	20	290	-	-	Discontinued		-	-	Alkali	Every 3 mo.	None	Could go 8,000 hr between washings
Dieppe-Deauville	None	-	-	-	Dieppe-manual brush Deauville-steel shot	- -	2-3 kg Additive every 2-3 hours				None	-	-	Firetube boilers Deauville uses additive
Gothenberg	21 steam blowers	1/shift	22	313	-	-	10	Less Frequently	22	313	None	-	Alloy Steel angles	Shields need replacement every 6 mos.
Uppsala	None	-	-	-	Shot, Aluminum	Continuous	-	-	-	-	None	-	-	-
Horsens	None	-	-	-	Powered Rotary Brush	Every 2 weeks	-	-	-	-	None	-	-	Firetube boiler
Copenhagen:Am-W.	Steam	-	-	-	Shot	-	Tried Sonic Vibration, rapping				None	-	-	3 passes brushed manually

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TABLE U-4. METHODS USED TO CLEAN TUBES AND WALLS OF EUROPEAN REFUSE-FIRED ENERGY PLANTS.

A. Automatic Remote Controlled Soot Blowing

1. Fixed Position - rotary motion
2. Retractable Positions - spiraling motion
3. Steam
4. Compressed air

B. Mechanical Rapping

1. Automatic continuously operating hammers
2. Sledge hammering of boiler tube bundles by operator
3. Unbalanced compressed air vibrator

C. Automatic Shot Cleaning

1. Falling aluminum shot
2. Falling steel shot

D. Chemical Additive

1. Blowing inorganic "Gamlenite 8" dust to soften deposits

E. Non-Chemical and Manual Cleaning of Cooled Furnace

1. Compressed air manually operated nozzles
2. Small miscellaneous brushes
3. Manual scraping
4. Pneumatic hammering
5. Powered rotating wire brush for fire-tube boiler

F. Chemical and Manual Cleaning of Cooled Furnace

1. Soak with alkali, sodium carbonate or other chemicals
2. Rinse with high pressure water jets
3. Soak again
4. Rinse again
5. Scrub with brushes, pneumatic hammers and other tools
6. Sand blast difficult deposits.

mm (0.02 in). Emphasis should be on rapid acceleration of the tube rather than on greater amplitude to dislodge the deposits.

Baden-Brugg, Switzerland

At Baden-Brugg steam-actuated soot blowers are available but are not used because of the widespread experience that steam soot blowers accelerate tube wastage. The vertically hung superheaters are cleaned manually on weekends every 6 weeks by means of compressed air nozzles inserted through the access doors.

Duesseldorf

At Duesseldorf, excessive tube wastage because of soot blowing has occurred only in the economizer. The plant manager emphasized the importance of following in safe soot blowing:

- Steam lines must be well drained to avoid blasting slugs of water against the tubes. Tubes are blown once per shift.
- Protective shields are very successfully used to guard against soot blower erosion.
- Steam jet pressure must not be too high.
- A thermocouple in the steam line can be used as an operating guide. The temperature should be well above saturation temperature to avoid blowing slugs of water when the soot blower is turned on.

The entire boiler is water cleaned in Units No. 1-4 every 2,000 hours. No. 5 is similarly cleaned every 5,000 hours. At first, the tubes are sprayed for 10-12 hours at the rate of 10 m^3/hr (44.0 gpm) to soak the deposits. Then the weakened deposits are removed the next morning by means of a high pressure water jet.

Wuppertal

During initial operation, water-washing of the boiler heating surfaces at Wuppertal was used periodically for cleaning. However, this posed some threat through soaking of the refractory coating in the lower part of the radiation chamber and combustion chamber. Water-washing is no longer used. Instead, every 3000 to 4000 hours the surfaces are brushed clean manually. So far there has been no slag buildup anywhere in the system, hence, only fine deposits need to be brushed off. This is unusual, since many other waste-burning furnaces require periodic cleaning of heavy deposits of fused ash and slag that adheres strongly to the sidewalls of the combustion chamber. We can only conclude that these four relatively new furnaces are not being fired as intensely as are many others, hence the deposits of ash are soft and not fused.

The superheater is cleaned by steam blowers which initially operated at 15 bar (1500 kPa) (218 psig). However, because of well-known experiences elsewhere with the high velocity of steam blowers having a cutting or erosive action or adjacent tubes, these blowers are now operated at a reduced pressure of 10 bar (10,000 kPa) (145 psia). Also, the tubes likely to be eroded by the steam are covered on the exposed side by 6-mm thick (0.24 in) half-round steel shields made of Sicromal. So far the shields tried of Sicromal 8 to 9 did not last long. Sicromal 10 seems to be better. Table U-2 shows the composition and properties of Sicromal.

Krefeld

Because most of the energy from the burning refuse at Krefeld goes to drying sludge the horizontal superheater is small. It has only one soot blower. At the time of the interview, Spring 1977, there had not been enough time to accumulate experience.

Paris: Issy

Corrosion difficulties from soot blower operation at Issy have caused them to turn to periodic manual scraping of the superheaters.

Falling steel shot are used to clean the 4 banks of economizer tubes.

Zurich-Hagenholz

The Hagenholz plant users compressed air soot blowers at 15 bar (1655 kPa) (240 psi). An isolated case of superheater tube erosion or corrosion occurred when a nozzle on a fixed position rotary soot blower manufactured by Forest and Bergaman of Bristol, Belgium, fell off. As a result, compressed air blew directly onto the tube sides. The nozzle failure was detected after about 8000 hrs operation and the tubes were inspected. None of the superheater tubes was burst but they had sufficient metal wastage to motivate replacement, so, 20 tube sections, averaging 5 m (16 feet) per tube in length were replaced. There have been no sootblower problems since.

The compressed air sootblowers are used daily. The two air compressors supply a 1500 m^3 (52,940 ft^3) air tank with air at a 30 bar (450 psig). The air released at the sootblower nozzle is at 15 bar (225 psig). Officials expressed their preference for superheater soot-blowing with compressed air over steam even though the air compressor costs about SF 250,000 ($124,378).

Every 4,000 hrs, each Hagenholz boiler is manually cleaned by the Hutte Company of Recklinghausen, West Germany (near Essen). Four or 5 men spend 7 or 8 days cleaning one boiler. An alkali solution is used. Sandblasting may be used for selected, hard-to-dissolve deposits. The procedure is basically as follows for most deposit areas:

1. Spray alkali (soak, no pressure)
2. Rinse with water
3. Spray alkali (second soak)
4. Rinse with water
5. Scrub with brushes and other tools
6. Sandblast difficult deposits

Cleaning all the tubes (walls and bundles) in all four passes normally costs about 25,000 SF ($10,000). The dirty water coming out at the boiler bottom has a pH of about 2 so chalk must be added.

Plant staff have been experimenting with an "unbalanced compressed air vibrator" for cleaning the superheater. Every two minutes, the upper three bundles are vibrated. Every second or third months, the procedure is interrupted for a half day.

At the old Hamburg: Borsigstrasse plant, the bundle wall anchors are hit with a sledge hammer once per week.

The compressed air sootblowers are fixed-rotary (and not retractable). Hence, the nozzles are always oriented properly and not directed against the steam tubes. The sootblower jets are fixed just underneath the tube bundle.

The economizer is cleaned with falling steel shot (and not by soot-blowers) thus avoiding potential problems.

A recent check in April, 1977, after 30,000 hrs operation, showed that the original upperheater tubes had metal wastage of only 0.3 mm. The water tube walls of the second pass had only 0.1 to 0.2 mm metal wastage on the original tubes.

Hamburg-Stellinger-Moor

The retractable sootblower at Hamburg removed tube deposits too efficiently and thus increased the rate of exposed metal wastage. Also there was erosive abrasion by the ash in the high velocity flue gases. To combat these problems, in April 1977, a series of 50 mm (2 inch) curved shields were welded next to each other along the front surface of the first row of superheater tubes as seen in the several portions of the previous Sicromal 10, a high temperature alloy material was used for these curved plates. About 1 or 2 mm separate each shield. The last shield at the bottom of the superheater tube is extended further straight down and thus away from the tube. This provides some protection of the very bottom of the tube. At the tube's upper section, the same material is not welded but formed in a U shape and bolted from the back side.

Because the economizer tubes would change position due to thermal stresses, the wall-attached sootblower would then send high pressure steam directly onto the tubes. These moving economizer tubes have been the cause f four or five tube failures per year. To alleviate this problem, S-M has decided to mount the sootblowers on the economizer bundles themselves.

Convection section near the fixed position sootblowers had been a serious problem. As has been mentioned by several different plant managers, reducing the sootblower activity can provide increased tube life with no increase in costs. The only penalty is a modest decrease in thermal efficiency. Decreasing sootblower activity is recommended especially during seasons of "excess" steam production. Methods exist for reducing activity, frequency, and pressure.

First, as at S-M, many plants reduce the soot-blowing frequency. In this case, many blowers that had been blowing once per shift are now scheduled to blow 1 to 3 times per week.

Secondly, at Hamburg, the pressure has been reduced from 18 bars (1800 kPa) 260 psi to 14 to 16 bars (200 to 230 psi).

The actual determinataion of blowing frequency is a function of where the boiler is in its 4,000 hour cycle between major overhauls. If operation is in the first 1000 hours after maintenance, they blow only one third as often as before. If, however, they were in the last 1000 hours, they blow half as much.

The Hague

In the newest unit, No. 4, at The Hague, a widely spaced superheater tube-bank has been installed. With this wider spacing it is estimated that the unit could operate about 8000 hrs before chemical cleaning of the tube deposits would be necessary. However, tube thickness is checked once per year, hence cleaning by washing is done once a year to enable the tube-wall thickness check to be made.

At first the soot blowers, operating at 20 bar (2000 kPa) 290 psi, were used once per shift, but this caused tube wastage. Instead the entire boiler system is now cleaned about every 3 months by a contractor: FA Conservator of Rotterdam. They use high pressure jets of sodium carborate solution to remove the tube deposits.

Dieppe and Deauville

The low-pressure, sludge drying and co-disposal plants at Dieppe and Deauville use vertical firetube boilers which are normally cleaned manually. At Dieppe the cleaning cycle is every 3 months. Each boiler is drained and completely cleaned internally and externally by the plant staff using brushes and other small tools.

The Deauville firetube boilers are of the same design, manufacture, and capacity as at Dieppe, but the flyash deposits are cleaned from the Deauville boiler tubes by falling steel shot pelllets, which are fed periodically into the top of the boiler. After the shot falls through the tubes, they then fall along with the dislodged ash into a conical hopper situated directly beneath the boiler. The shot are then separated by gravity from the lighter flyash and the shot are recirculated in a high velocity air stream to the top of the boiler for another cleaninng cycle.

In addition to this cleaning process, the experience had been that every 10 weeks it was necessary to hand clean persistent ash deposits from the tube surfaces. However, in April, 1977, the staff began regularly to blow into the furnace a fine inorganic dust known as Gamlenite 8 in order to soften the ash deposits in the tubes so that the shot would remove them and hand cleaning would not be necessary, About 2 to 3 kg (4.5 to 6.5 lb) is blown in with air every 2 or 3 hours. According to the staff, this additive has so far been entirely successful in making the tube deposits so soft that they are readily removed by the shot, thus eliminating the need for hand cleaning.

Gothenberg

The water-tube boilers at Gothenberg produce saturated steam except for a small superheater to supply steam up to 3000 (572 F) for soot-blowing only. Originally each boiler was equipped with 21 blowers. These probably cleaned the tubes too well and some tube corrosion occurred. Accordingly 11 of the 21 blowers were removed and the remaining 10 are now used less frequently. Also on the tubes directly opposite the blowers half-round alloy steel shields 1 mm (0.040 in) thick were tack welded to the tubes. Later these were replaced by alloy angle irons strapped to the tubes. The alloy is 20 percent Co, 10 percent Ni. The shields have been successful in protecting the nearby tubes from soot-blower action but need to be placed about every 6 months.

Uppsala

All three water-tube boilers are cleaned at Uppsala by falling aluminum pellets. Figure U-35 shows a part of the pellet recirculation system. The pellet storage bin holds 30 kg (66 lb) of pellets. Owing to attrition, about 15 kg (33 lb) of pellets must be added per month. The melting point of the pellets is about 750 C (1,382 F). The maximum gas temperature entering the boiler is about 700 C (1,292 F).

About every 3 weeks, it is necessary to clean dust accumulations up to 50 mm (2 in) thick at the entrance from the afterburner chamber of Boiler No. 3. The deposit is easily brushed away. Steam jets will be tried to replace brushing. No other boiler cleaning is required.

Horsens

The Horsens plant uses a simple vertical firetube boiler which contains 540 tubes, 57 mm in diameter (2.25 in) and 4.5 m (14.8 ft) long. The top of the boiler is accessible so that once every 2 weeks all of the 540 tubes can be cleaned of soft ash deposits by means of a powered rotating wire brush. This takes 6 to 7 hours every Monday morning at the same time that the air openings in the grates are being cleaned and the siftings are being removed from beneath the grate.

Copenhagen:Amager and West

The large, hot-water, water tube boilers at the 2 similar Copenhagen plants are cleaned by a variety of methods. At Amager, tube cleaning has been an experimental matter. Sonic vibrating, mechanical rapping and soot blowing have been tried. Now falling steel shot is used routinely, On shutdown the 3 open passes are brushed manually.

The steel shot cleaning system was supplied by Eckstrom of Stockholm, Sweden. As at Amager, the West economizers are fin-tubed with small spaces. The spaces and corners became so clogged with flyash and steel shot, that they will have to be replaced. Because of the clogging, the economizers at both Amager and West have set the overhaul schedule for the whole plant. Until the economizers are replaced, the unit will continue to shutdown every 1,500 to 2,200 hours. The manufacturer's original recommendation of cleaning every 3,000 hours would have been mainly to restore efficiency. The economizer is cleaned manually with brushes.

Unfortunately, shot cleaning was not in the original design. Therefore, on retrofit, the falling shot was down--concurrent to the flue gas. In future economizer designs, both the gas flow and the steel shot flow will be downward.

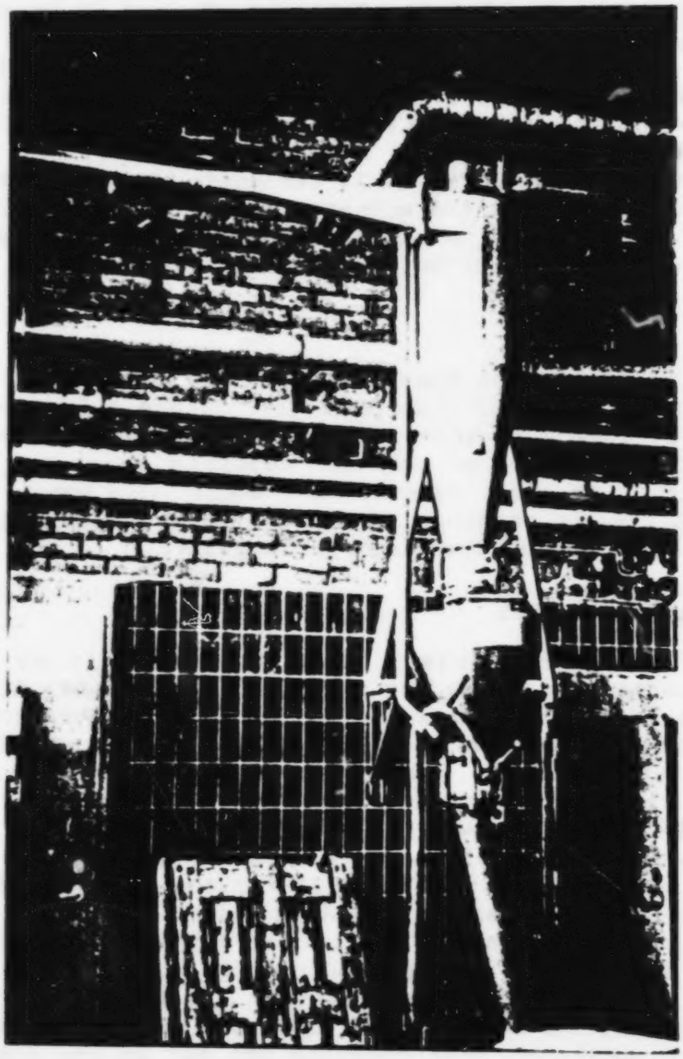

FIGURE U-35. SHOT PELLET CLEANING FEED SYSTEM AT UPPSALA (Battelle Photograph)

Metal Wastage (Corrosion and Erosion) of Boiler Tubes

Experience with Fossil Fuels

In fossil-fuel fired plants most boiler and superheater tubes undergo such slow corrosion that tube wastage is virtually not a problem. Usually the metal oxide layer on the fireside protects the tube from rapid corrosion. However, in the 1940's when coal-fired boilers were being pushed to meet war-time demands for power, wall tube attack by alkali trisulfates became common. It was solved by blanketing the walls with air to reduce SO_3 concentrations. In the late 50 's in superheaters on coal-fired boilers operating with metal temperature at about 1100 F, the alkali iron trisulfates again caused rapid attack. A reliable solution to that problem has not been achieved as yet.

Experience with Refuse as Fuel

Later, in the early 60's, when refuse-fired boilers began to produce higher temperature steam, over about 204 C (400 F), wall-tube and superheater corrosion became a difficult problem because of the chlorine in the refuse. There have been many incomplete theories advanced to try to explain this chloride attack. Gradually some practical concepts have been evolved that, when applied, have greatly reduced and, in some cases, virtually eliminated wall-tube and superheater corrosion, even when operating at a final steam temperature of (410 C) 770 F. There are still many conflicting concepts on corrosion that are widely held. This section will attempt to describe a plausible composite of some of those ideas and experiences.

Oxidation-Reduction Reactions

A common misconception that persists today despite growing contradictory experience is that if reducing conditions can be entirely avoided in the furnace gases, high-temperature corrosion will be avoided. This might be true if the tubes were always bare, rusted steel. But they are not. They are quickly and heavily coated with tenacious deposits of potentially active flyash. After a short time these tight deposits of ash become thick enough and dense enough to almost completely isolate the steel tube surface from the gases, whether reducing or oxidizing. At this point diffusion rates of gases, such as O_2, SO_2, or CO through the deposits will control the corrosion reactions. Carbon-containing particles trapped in the deposit may lead to highly reducing localized conditions that could result in loss of metal by sulfidation, particularly with nickel-rich alloys.

The belief that alternately oxidizing and reducing conditions lead to accelerated attack of the metal is based on observations of incinerators where flames are in contact momentarily with heat-absorbing surfaces, so that the atmosphere in contact with the tube contains oxygen at one moment, and CO or H_2 in the next moment. The difficulty here is that the rate at which oxidizing or reducing reactions occur with the normal oxide film on the tubes is not known or even well understood. Until data are available on the time of exposure to oxidizing or reducing conditions as they exist in furnace gases, necessary to cause a perceptible change in the oxide film in a tube, this oxidizing-reducing hypothesis must be applied with caution.

Effect of Soot Blowing

Most plant operators have learned that cleaning off the ash deposit and the underlying oxide scale too well and too often greatly increases tube wastage. This experience demonstrates the importance of building up a protective deposit on the tube metal surface and retaining it there. Corrosion rates of superheaters where soot blowing is too frequent will equal the high short-term rates experienced on new, clean surfaces. This corrosion is the result of both oxidation and chloridation of the metal surface.

A Proposed Corrosion Mechanism

The research on corrosion since 1969 for EPA by Miller, Vaughan, Krause and Boyd* has shown that the important factor is: what goes on inside the layer of ash adhering to the metal tubes.

Dale Vaughan, recently retired as one of the leaders of that research at Battelle-Columbus, has summarized the work in an internal memo as follows:

> "The boiler tubes are exposed to the normal combustion gases CO_2, CO, HCl, small amounts of sulfur oxides and organics, excess air, plus vapors and solids of inorganic compounds. The initial reaction is undoubtedly the formation of a thin oxide layer on the boiler tube which is quickly coated with a deposit containing large amounts of chlorine identified as a mixture of potassium and sodium chloride with smaller amounts of heavy metals. Hence, the tube metal is no longer exposed to the gaseous combustion products but instead is exposed to the deposit and/or the products of its reaction with the gases.Studies of deposits after long exposure to incinerator combustion products have shown that the chlorides are converted to sulfates and that the chlorine content is thus reduced significantly except at the metal surface where $FeCl_2$ has formed. The iron oxide layer is no longer in contact with the metal surface, but instead chlorine is now the corrosive species."
>
> "Our corrosion data show that wastage of carbon steel increases rapidly at about 400 F and again at 800 F. The first increase is attributed to chloridation and the second to sulfidization. The first increase coincides with the rapid attack of iron by elemental Cl_2 as shown by Brown, DeLong and Auld. ( ) Furthermore, their studies show that rapid attack of iron by HCl does not occur until a temperature of about 900 F. Therefore, it is doubtful that the HCl content of the combustion products is a significant contributor to metal wastage in the temperature range where chlorine is the corrosive species. However, as expected, Cl_2 has not been detected in combustion gases but this does not eliminate its existence as a product in the conversion of metal chloride to metal sulfate. This occurs mainly in

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*Krause, H.H., Vaughan, D.A., Miller, P.D., "Corrosion and Deposits from Combustion of Solid Waste, Part II, Chloride Effects on Boiler Tube and Scrubber Metals,` ASME Paper 73-WA-CD4, November, 1973.

*Vaughan, D.A., Krause, H.H., and Boyd, W.K., "Corrosion Mechanisms in Municipal Incinerators Versus Refuse Composition", Proceedings ASME Conference on Present Status and Research Needs in Energy Recovery from Wastes, Hueston Woods, Ohio, Sept. 1976.

deposits which are retained on boiler tubes and exposed for sufficient time to the hot gases containing low concentrations of sulfur oxides. When the Cl_2 is released from the metal chloride deposits at the tube surface the attack is very rapid. However, our studies have shown that with a sufficient increase in sulfur in the fuel, metal sulfates form rather than metal chlorides in the fuel bed and combustion chamber, little or no chlorine is found in the deposit, and the metal wastage is markedly decreased even though the HCl in the combustion gases is increased some. SO_2 emission may increase depending on the fuel mixture involved."

Thus, the major corrosive factor in refuse-fired boilers is chloride attack. This goes on whether the furnace conditions are oxidizing or reducing. That is, even when the furnace atmosphere is on the oxidizing side, conditions within the mineral deposit at the tube surface may be oxygen-free. Where chlorine, HCl, or sulfur are formed right next to the tube metal, attack on the metal can occur, and $Fecl_2$ or FeS will be the corrosion products.

For example, electron probe and X-ray diffraction analysis of the layers on corroded tubes shows that compounds exist there which could only persist under reducing conditions, but at the same time, furnace gas analysis in the vicinity usually shows oxidizing conditions.

In general, the European practice has been to "solve" the wall tube corrosion-erosion problem by covering the tubes with silicon carbide. Hence, the remaining corrosion problem is primarily on the superheaters. Although there may be momentary excursions into reducing conditions in spots around superheaters, it seems to be unlikely that many superheaters are subjected to severe and massive flows of reducing gases. Yet the superheater corrosion is common. And so are chlorides common in refuse--the 0.5 percent in the bulk refuse quickly accumulated to become several percent of the tube deposits, hence, their corrosive action at high temperatures.

To summarize this subject: even in the very common condition with refuse burning where oxidizing furnace gases are typical, the action of chlorine and HCl released in the zone next to the tube metal will be very corrosive. One potential means for protecting the tubes has been found. By study of steel probes inserted into incinerator gases, Vaughan and co-workers have discovered that if the sulfur content of the refuse is increased to two percent, the chlorine from the burning waste does not appear in the ash deposits on the tubes, hence, the chlorine is not there to corrode.

Another approach to reducing superheater corrosion has been to place the superheater as far away as possible from the furnace flame, thus giving the gases time enough to complete combustion and to cool to a safe temperature level. However, at gas temperatures above 1000 F (538 C) this protection is thought to be less effective than adding sulfur.

The authors recognize that some of the foregoing discussion of corrosion is not fully consistent withh the views of many respected authorities who are experienced in this field. Not all of the corrosion mechanisms have been fully postulated and proven in acutal practice. Accordingly there is room for well-informed opinion involving potential disagreement on the causes and abatement of tube wastage. However, despite the existence of vexing discrepancies in viewpoint we are much impressed that the operators at the 15 plants visited have achieved practical control of tube wastage to quite acceptable levels. There is room for improvement but the current level of control indicates that good progress has been made toward practical control of the problem.

Reasons for Minimal Tube Corrosion

The most corrosion-free plant visited on this project was Zurich:Hagenholz. Although the superheated steam is produced at (420 C) 788 F, wall and superheater tube corrosion has been minimal compared to other plants operating at such high temperatures. There appear to be many reasons for this good experience. Most of those reasons were elicited as follows from discussions with the plant designer, operator and builder. Other plants provided additional points which are included in the following:

Management

1. In the original plant design corrosion is reduced if there is no set cost limit, hence the best (efficient and reliable) boiler that money could buy is selected.
2. Overdesign reduces the chance for overheating. A widespread viewpoint: "You ought to build the best plant possible and the run it at 80 percent of capacity".
3. Excellent management ensures that the properly designed plant is observed, monitored, and controlled to run as it was intended.
4. Rotating job positions for each man enhances his understanding of the complex plant and his spirit to run it properly.

Automatic Control

5. Well-placed and sensitive controls send instantaneous furnace roof temperature readings to the feeder and grate controls. As a result, flue gas, metal surface, and steam temperatures are kept within limits and high temperature corrosion is avoided.

Start-up Procedures

6. The use of a standby boiler (Number 2 oil or waste oil) to be started before the refuse is fired can be used to heat the primary underfire air in a steam air preheater to 150 C--above the dew point temperature.
7. The standby boiler can also supply steam to the refuse boiler to preheat the tubes above the dew point tempereature to avoid wet corrosion of the boiler, electrostatic precipitator, or the stack.

Refuse Handling

8. The crane operators take care to mix refuse in the pit so that a more uniform fuel is available that will not cause wide swings in flue gas temperatures.

9. Positive refuse feeders introduce controlled amounts of refuse into the furnace and minimize uncontrolled cascading that would cause poor burning and formation of potentially harmful CO.
10. Various grate actions gently turn and distribute the refuse for exposure to the flame combustion air.

Secondary Air

11. Preferably front and rear-wall overfire-air jets should be aimed to develop a turbulent pattern low in the furnace. Flame lengths are kept short and do not rise far into the first pass.
12. Side wall air jets are less effective in providing full furnace mixing. (However, this is not meant to criticize Kunstler or Didier air-wall blocks).
13. Secondary air up to 500 to 600 mmWs (20 to 24 in) causes intense turbulence so that virtually all CO is eliminated before the flue gases leave the combustion chamber. Alternating reducing - oxidizing atmospheres are eliminated.
14. At Zurich the secondary (overfire air) from the neighboring rendering plant "may" contain reduced sulfurs, etc., that may reduce corrosion by forming sulfate deposits. However, the concentration of sulfur is believed to be low and more investigation is needed to confirm any hypothesis. The Ammonia concentration is often high and its effect, if any, on corrosion is not known.

Furance Walls

15. The only successful protection for the walls of the combustion chamber and the lower portion of the walls in the first pass is to coat them with Silicon Carbide that was properly supported by studs.
16. A large, open, water-tube-walled second pass helps to protect a superheater from being overheated.
17. The flue gases flowing in a large second pass flow at reduced velocity which reduces the erosive effect of the particulates in the gas as it enters the first row of superheater tubes.

Superheater

18. A superheater located in the third pass (and not the first or second pases) faces cooler flue gases, with little or no CO.
19. If the superheater tubes are sinuous and horizontal, with downward flow, stagnant steam pockets are less likely to occur to interrupt heat transfer.
20. The use of in-line superheater tubes (and not staggered) allows flue gases to pass more easily.
21. Low alloy and high alloy steels at the most exposed locations help to minimize superheater corrosion.
22. Close control of the attemperator (desuperheater) between the superheater bundles helps by keeping steam temperature nearly constant.

23. Simple alloy steel shields clamped to the most exposed tubes are easily replaced during routine maintenance and are in widespread use for minimizing tube wastage.

Economizer

24. Economizers may also be equipped with a shield on the tubes that are most exposed.
25. The use of a large economizer is helpful to recover energy and to reduce flue gas temperatures entering the electrostatic precipitator.

Boiler Cleaning

26. Many plants use vibrators or hammers to shake deposits from superheater bundles.
27. One plant uses compressed air (and not steam) sootblowers in the superheater section. Thus, injurious slugs of water lying in inactive sootblowers cannot harm the tubes upon startup.
28. If the sootblowers in the superheater section are fixed-rotary (and not retractable), the nozzles are always oriented properly and not directed right against the steam tubes. Also the sootblower jets can be positioned just underneath the tube bundle.
29. A common practice is to manually clean the boiler fireside surfaces with an alkali every 4,000 hours.
30. Sandblasting during cleaning should be limited to removing only difficult tube deposits.
31. In some cases with lower flue gas temperatures in the first 1000 hours after cleaning, if much sulfur is present a ferrous sulfate $FeSO_4$ might form on the tubes instead of the more harmful $FeCL_2$.
32. Many economizers and some boiler passes are cleaned with falling steel shot (and not by sootblowers) thus avoiding potential erosion and bare-tube corrosion problems.

Steam Condensers

Large quantities of steam are discharged in either water-cooled or air-cooled condensers at 6 out of 15 plants as listed below:

Plant	Mode of Cooling Steam
Werdenberg	Air
Baden - Brugg	Water
Wuppertal	Air
Hamburg: Stellinger-Moor	Air
Zurich: Hagenholz	Air
Gothenburg: Savenas	Air

Werdenberg - Liechtenstein

Figures U-36 presents two views of the small roof top air cooled steam condenser at Werdenberg. Due to the complex energy scheme, most steam produced is effectively used: little needs to be condensed.

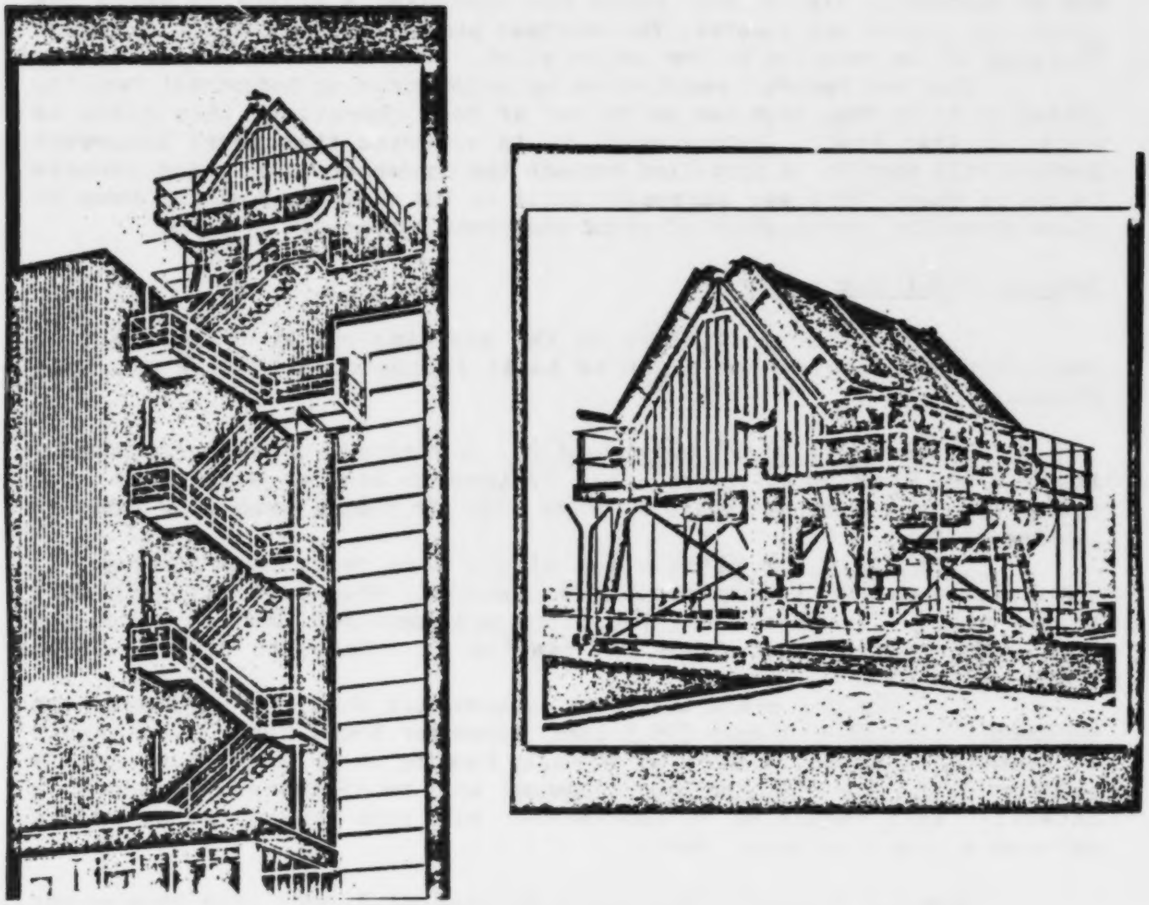


FIGURE U-36. Two views of Air-cooled Condenser at Werdenburg.
(Courtesy of Widmer and Ernst)

Baden - Brugg

The steam is condensed with heat transfer to water drawn from the adjoining Limmat River. The condenser is cleaned once every 3 months.

Wuppertal

The largest set of air-cooled steam condensers seen on the tour was at Wuppertal. Figure U-37 shows the condenser's underside where the large fan blades are located. The overhead plant insert shows the condenser (labeled 10) in relation to the entire plant.

The new Federal regulation on noise near an industrial facility limits it to 35 dba. With two units out of four operating, this plant is close to that limit. Accordingly, it is expected that sound absorbent louvers will need to be installed beneath the condenser if a third furnace is to be used. This was purposely built in the elevated position shown to allow space for installation of sound absorbent surfaces.

Hamburg: Stellinger - Moor

The chronological story on the Stellinger - Moor condenser is important to systems that might be built in the colder North American climates.

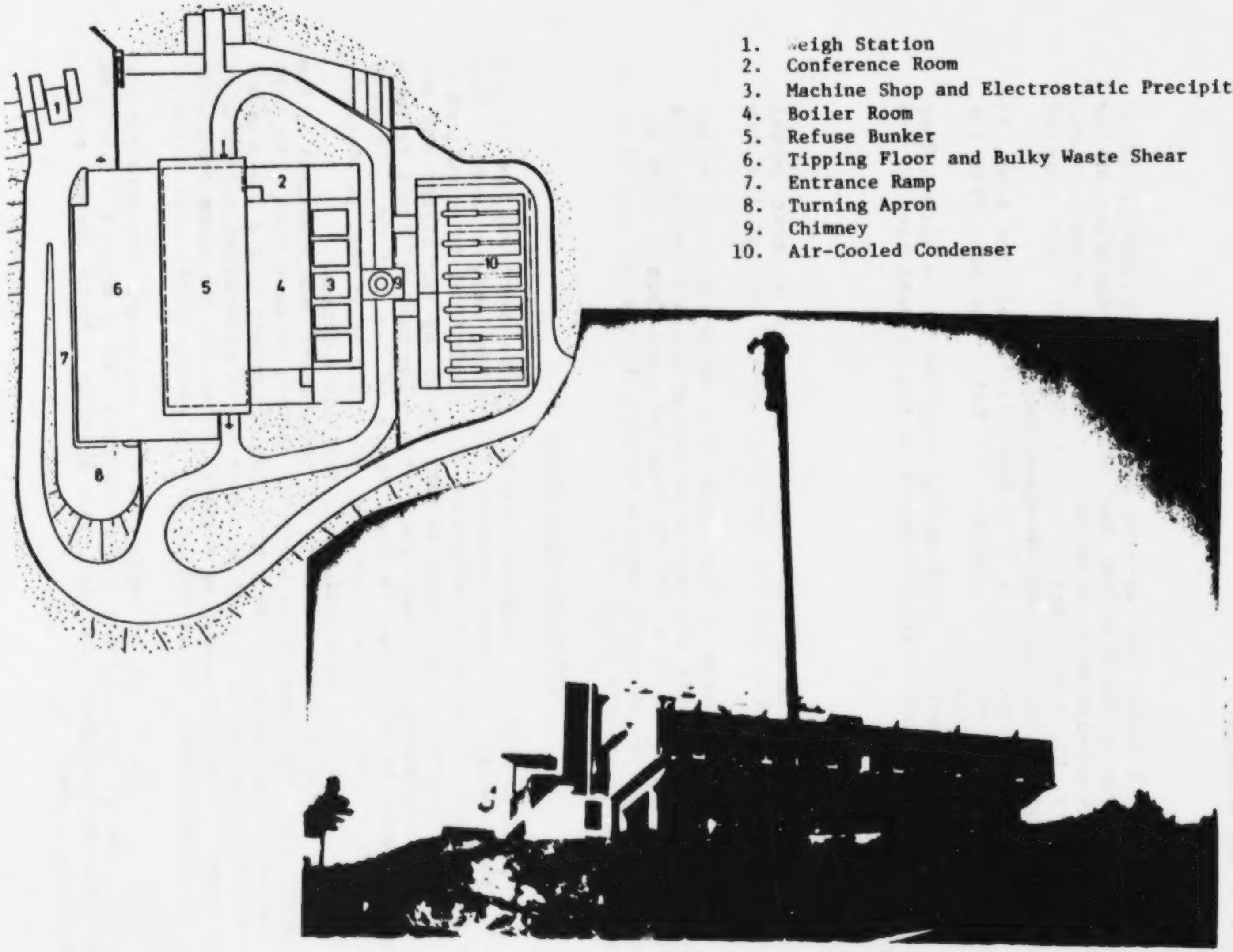
Stage 1 (Original Construction). In contrast to Martin's Chicago, Illinois and Harrisburg, Pennsylvania systems in America with horizontal tubes, a common European practice is to have air cooled condensing tubes in sloping roofs.

Originally the plastic fan blades were reset twice per year. In the winter when not as much cooling was needed, they were set with very little pitch. In the summer, the pitch was increased. Unfortunately, the high summer pitch would cause the plastic fan blades to deform, slip, break, or fall out.

In the event that both turbines are down, the condensers can condense a limited 45 tonnes (49.5 tons) steam per hour. Thus, if a single 88 tonne/hour capacity turbine normally running at 60 tonne/hour capacity suddenly fails, the 45 tonne/hour condenser will be 15 tonne/hour short in capacity. This remaining 15 tonnes/hour will pass through the throttling valve at a very high noise level.

Stage 2 (Changing Fan Speed Instead of Pitch). The problem was resolved by setting the pitch low for winter needs and then not changing the pitch throughout the year. In the summer, the motor speed is nowraised. Maintenance on the fan has now been greatly reduced. They now overhaul and balance the fans every two years. They clean the system every early summer with high pressure water.

Stage 3 (Freezing Tubes Requiring More Thermocouples).The sloping roof at Stellinger-Moor experienced freezing in six of its condenser fin tubes once when it was - 20"C (-6° F). The single thermocouple was located on one of the four headers and was on the protected leeward side of the condenser. As a result, the reading was always above the danger level.



1. Weigh Station
2. Conference Room
3. Machine Shop and Electrostatic Precipitator
4. Boiler Room
5. Refuse Bunker
6. Tipping Floor and Bulky Waste Shear
7. Entrance Ramp
8. Turning Apron
9. Chimney
10. Air-Cooled Condenser

FIGURE U-37. UNDERSIDE VIEW OF WUPPERTAL PLANT HIGHLIGHTING THE AIR-COOLED STEAM CONDENSERS AND THE STACK (Battelle Photograph)

Unfortunately, the chill factor (temperature and wind velocity) was much worse on the windward side and freezing occurred unnoticed. The first sign of a problem was when the electrical turbine tripped out. They now have four thermocouples, one for each header and these have readings on both sides of the condenser.

Zurich: Hagenholz

Figure U-38 shows the roof-top condenser at Hagenholz. Large vertical louvers, made by GEA of Bochum, West Germany, are installed on the roof wall around the air-cooled steam condenser fan bottoms to abate noise.

Separately, the V-belt drive on the Condenser fans started squealing at low speeds. They now have two-speed motors.

The condensing capacity is 75 tonnes (82.5 tons) per hour. At present they condense about 40 tonnes (44 tons) per hour from the extraction condensing turbines.

Previously, Hagenholz had freezing problems in the Winter. They now feed steam first to what would otherwise be the coldest part of the condenser.

Gothenburg: Savenas

Savenas was designed with utmost concern for architecturaal features, aesthetics and concern for the environment. One of the key concerns was noise.

To suppress the noise of the large fans which supply air to the air-cooled condensers, they are enclosed in perforated louvered walls. This has reduced the noise level 100 m (328 ft) from the plant from 58 to 50 dB. Noise regulations now for new plants require 45 dB(A) in the day and 35 at night. See vertical louvers in Figure U-39.

Steam-to-Refuse Ratio

A useful number in judging overall plant performance is the evaporation ratio: weight of steam produced divided by refuse fired. This ratio is particularly useful as an evaluation of a plant if it is calculated on an annual basis. However, it is subject to many day-to-day variations and can be particularly misleading when comparing plants. The most difficult variable to measure, or even to estimate, is heat vlaue of the refuse. In many communities, LHV (or HHV) is nearly constant, on others it is not, particularly where industrial refuse is a major and highly variable component.

Another variable among plants is the temperature (and pressure) of the steam produced. Although this can be precisely defined in each case, the heat content (enthalpy) of steam can vary more than 25 percent from a low-pressure plant for district heating to a high-pressure plant generating superheated steam for power. Thus, in comparing evaporation ratios, the steam conditions should always be considered, and we should try to evaluate the heat value of the refuse.

Table U-5 illustrates the variations that can occur. The data for the plant at Harrisburg, Pennsylvania are introduced for comparison because extensive data were available for that plant which is a Martin system, similar to many European plants.*

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*"Performance of Steam Generating Incinerator", Battelle Report to Harrisburg Incinerator Authority, 1974.

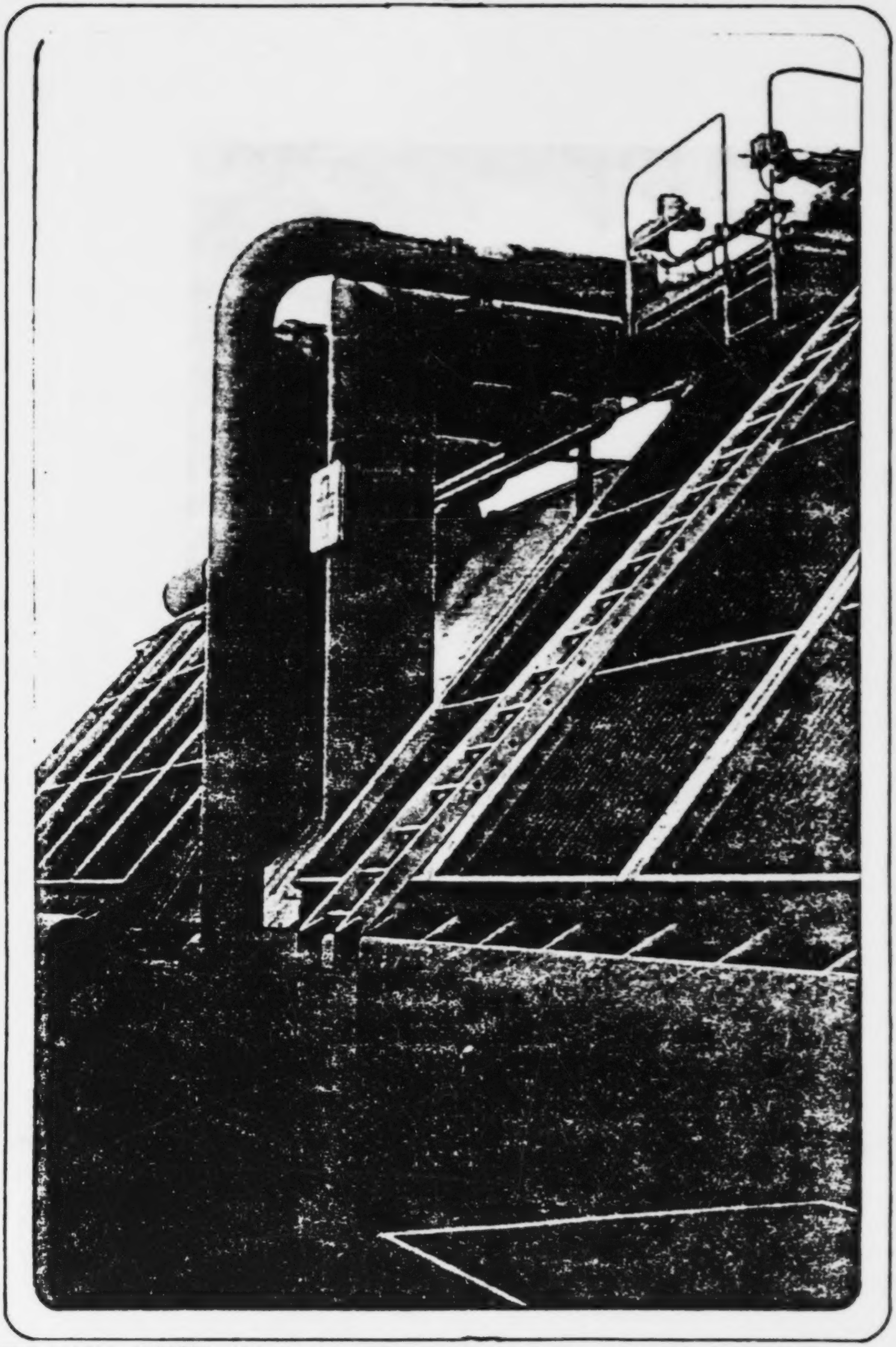


FIGURE U-38. SLOPING AIR-COOLED STEAM CONDENSER TUBES AT ZURICH: HAGENHOLZ (Battelle Photo)

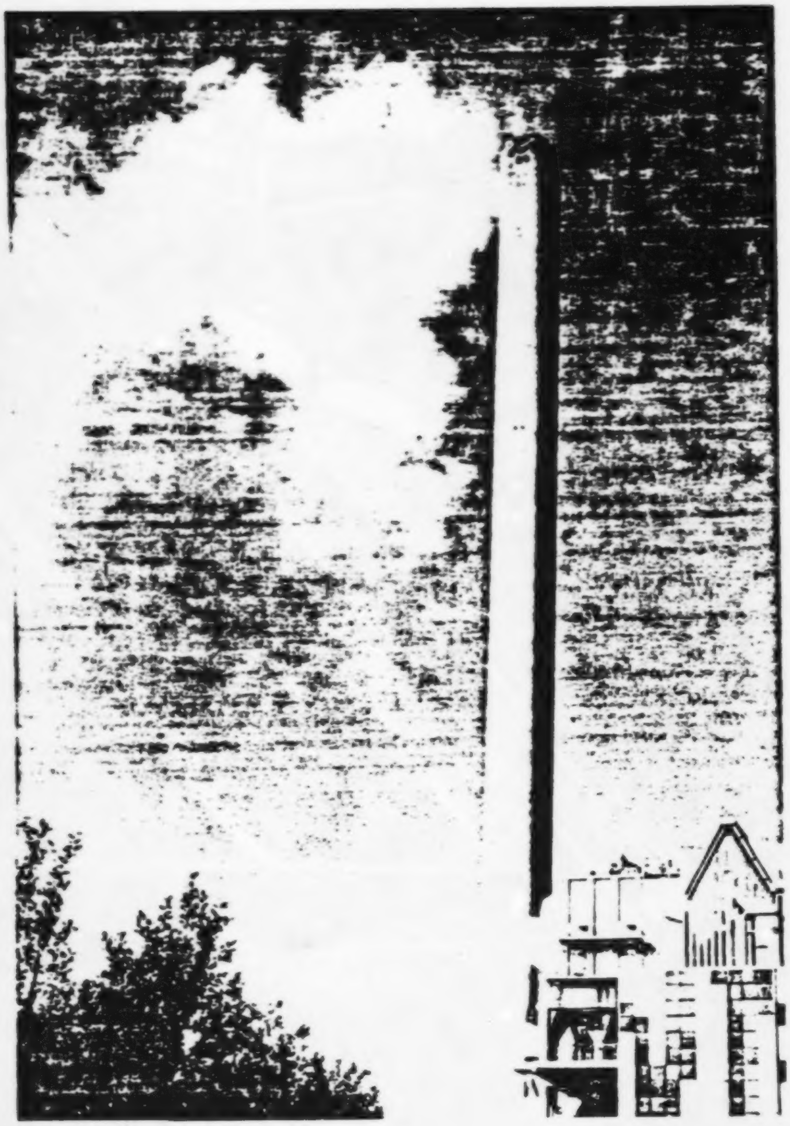


FIGURE U-39. LOUVERS BELOW INVERTED V-SHAPED AIR-COOLED STEAM CONDENSERS AT GOTHENBURG: SAVENAS (Battelle Photograph)

TABLE U-5. COMPARISON OF ENERGY RECOVERY

	Pressure		Temp.		Enthalpy of Steam Above 100F(37.8C)			Nominal Heat Value of Refuse (LHV)			Basis For Heat Value	Measured Evaporation Rate	Basis For Evap. Rate	Energy Production Rate Per Unit of Refuse			Efficiency Corresponding To The Indicated Value of Refuse %	Meas. Eff.
	atm	psia	C	F	KJ/Kg	KCAL/Kg	BTU/lb	KJ/Kg	KCAL/Kg	BTU/lb		Steam/Refuse		KJ/Kg	KCAL/Kg	BTU/lb		%
Harrisburg (PA.,U.S.A.)	18	270	289	480	2905	694	1249	8094	1933	3480 (1)	Anal.	2.56	Test (73)	7436	1776	3197	92	73
								8654	2067	3720	Anal.	3.09	Test (73)	8976	2144	3859	(?103)	82
								14049	3356	6040	Anal.	4.06	Test (73)	11795	2817	5071	84	66
								(41412)	(9891)	(17804)	(Oil)	(13.07)	Test (73)	-	-	(16324)	(92)	86
Gothenberg (Sweden)	25	367	224 (Sat)	436	2642	631	1136	9839	2350	4230	Estim.	3.09	'74 Yr.Avg.	8164	1950	3510	83	-
												3.13	'75 Yr.Avg.	8273	1976	3556	84	-
												3.18	'76 Yr.Avg.	8403	2007	3612	85	-
Hagenholz (Zurich)	37	544	420	788	3110	743	1337	9630	2300	4140	Estim.	2.58	'74 Yr.Avg.	8022	1916	3449	83	-
												2.41	'76 Yr.Avg.	7494	1790	3222	77	-
Dusseldorf (West Germany)	80	1176	500	932	3398	812	1461	7063	1687	3036	Anal.	1.77 (2)	'73 Yr.Avg.	6016	1437	2586	85	-
								6640	1586	2855	Anal.	1.65	'74 Yr.Avg.	5606	1339	2411	84	-
								7310	1746	3143	Anal.	1.88	'75 Yr.Avg.	6389	1526	2747	87	-
								7603	1816	3269	Anal.	2.00	'76 Yr.Avg.	6795	1623	2922	89	-

(1) The Harrisburg lower heat values have been estimated by subtracting 7% from the measured higher heat values. Source: Battelle Performance Measurements.

(2) The Dusseldorf production was actually about 5% higher than shown because internally used steam does not appear here.

The Harrisburg results are from short-term tests and the efficiencies shown are less consistent than for the other plants which are annual averages. In such short-term tests, errors in sampling and analysis of refuse produce inconsistencies. A particularly glaring example of the difficulty in reliable sampling of refuse is the erroneous efficiency of 103 percent for the "average" test at Harrisburg. The measured efficiencies in the last column were obtained by reference only to the boiler losses measured when burning oil only at Harrisburg and assumed to be the same for refuse.

The Gothenburg and Hagenholz plants are most nearly comparable. Although their evaporation rates are quite different (3.1 versus 2.5), their energy production rates (3,500 versus 3,400 Btu) produced per pound of refuse fired (8,141 versus 7,908 kJ/kg) are very similar. This close agreement while the evaporation rates are quite different is a clear demonstration of the unfairness that can result when comparing evaporation rates alone.

SUPPLEMENTARY FIRING OF FUEL OIL, WASTE OIL AND SOLVENTS

Oil and Waste Oil Co-Firing - General Comments

Number 2 Fuel Oil can be fired at five of the surveyed plants. Waste oil and/or solvents are fired at three plants. The oil firing capability is summarized in Table V-1.

The reasons for supplmentary firing are:

- Emergency backup
- Routine firing when refuse burning ceases on weekends
- Preheat the RFSG upon startup
- Keep boiler and electrostatic precipitator "hot" to prevent dew point corrosion when unit is down
- Supplmental fuel oil keeps furnace temperature at legal limit for destruction of pathogens, etc.
- Additional energy for routine uses.

In designing a total system, it is important to also consider the various reasons for not spending funds to install such supplemental firing features. Often, if the refuse to energy plant does not have continuous responsibility (as in the interruptible situation), the oil-fired backup will not be installed and the revenue per 1,000 pounds of steam is much less. Such situations include:

- Hot water to a district heating system where the system has other oil fired district heating stations.
- Industrial process steam to a user that maintains his own older conventional boiler ready for start up should there be aninterruption in the supply of refuse derived steam.
- Electricity to an eletric network where the loss of refuse derived electricity would have little effect on total network operations.
- Drying and burning of sewage that can be postponed several hours or days if the sludge storage tanks are large enough
- Energy to a physically adjacent conventionally fired energy plant where the total standby responsibility rests with the neighboring plant.
- A regional plan that mandates waste oil treatment and burning at a distant facility.

Only 5 of the 16 plants described were designed with key functions being served by fuel oil, waste oil or solvents.

TABLE V-1. USE OF SUPPLEMENTARY FUELS AT 16 EUROPEAN REFUSE FIRED ENERGY PLANTS

	Supplemental Fuel	Remarks
Werdenberg-Liechtenstein	No. 2 Fuel Oil	Standby Package Boiler Operates Unmanned on Weekends
Baden-Brugg	Waste Oil	Decanting Station Prior to Burning in Refuse Incinerator, Fired When Highest Electricity Revenue Rate
Duesseldorf	No.2 Fuel Oil	Used on Startup and Emergency
Wuppertal	None	No Need - Electricity Produced is Accepted Into Network Grid Intermittently
Krefeld	Waste Oil	
Paris: Issy	None	No need - Energy from Plant is fed into the large district heating and electricity networks
Hamburg:Stellinger-Moor	No.2 Fuel Oil	Used on Startup. Burning of Methane Gas from the Sewage Treatment Plant has been discontinued.
Zurich:Hagenholz	No.2 Fuel Oil, Waste Oil,Solvents	Separate boiler. for virgin No. 2 Fuel Oil. Separate boiler for decanted waste oil and solvents. Common steam header for all three boiler systems.
The Hague	None	No Need. Steam is intermittently fed to adjoining electricity power plant
Dieppe (and Deauville)	None	No Need. Drying and Burning sewage sludge can be delayed.
Gothenburg	None	No Need. Refuse Energy plant is only one module of largest district heating system in world.
Uppsala	None	No Need. Steam is intermittently fed to adjoining oil fired district heating plant.
Horsens	None	No Need. Sludge drying can be delayed. Refuse energy plant is only one module of district heating system.
Copenhagen:Amager	None	No Need. Steam is intermittently fed to adjoining oil fired, district heating plant. The predecessor 1931 plant at Gentotte co-fired with coal.
Copenhagen:West	None	No Need. Steam is intermittently fed to adjoining oil fired district heating plant.
Cologne (Hospital Waste)	No.2 Fuel Oil	The supplemental Fuel Oil keeps the furnace temperature at its legal limit necessary to destroy contaminated (non-tissue) hospital waste.

Oil and Waste Oil Co-Firing - Specific Comments

Werdenberg-Liechtenstein

Number 2 Fuel Oil. The energy demand is 7 days per week and the steam is produced from burning refuse only 5-1/2 days per week. Therefore, an oil-fired boiler was installed. This boiler is operated unmanned over the weekends.

Baden-Brugg

Waste Oil. Figure V-1 shows one of the two Elco air-atomizing oil burners which are mounted at the side of each furnace toward the rear. (Figure V-2 shows a similar sidewall burner at a hospital waste incinerator in Cologne, West Germany.) These burners are for the purpose of firing waste oil when available. About 50 percent of the waste oil comes for automoti ve serviice stations and 50 percent from industry. This includes some oil emulsions.

The waste oil is first received into a large heated concrete settling tank where it is heated by a heating coil to 50 C (122 F) and held for 3 days to allow solids to settle. From this tank it passes through a fine mesh filter to a day tank from which it is fired at varying rates up to a maximum of 800 kg/hr (1,761 lb/hr) per boiler. The filter must be cleaned every 2 or 3 months. Figure V-3 is a schematic of the process located parallel to the refuse pit.

Plant practice is to reserve the waste oil for firing when the refuse is wet or to dispose of the oil when all oil-storage space is filled. Also, at mid-day when the highest revenue can be realized from the sale of electricity, the waste oil may be used. When firing oil, both burners on opposite sides of each furnace are used. The burners require little maintenannce but are inspected and cleaned every 2 months. They employ light oil for a pilot flame. Some difficulty has been encountered with floatable substances that accumulate at the top of the waste oil settling tank.

Duesseldorf

Number 2 Fuel Oil. The only auxiliary fuel used at this plant is No. 2 fuel oil which is used only for start-up or in an emergency. In Germany, there is a legal requirement on incinerators that the combustion gases must attain a level of 800 C (1,472 F). If there is very wet refuse or some other cause for the furnace temperature to fall below that limit, the oil burners can be used to raise the temperature. Originally, Boilers No. 1-4 had three oil burners at the top-front-center of the furnace between the feed chute and the arch. Now there is only one burner per unit. The burner for No. 5 is on one side. Maximum oil capacity per burner is 0.4 tons/hr (130 gal/hr).

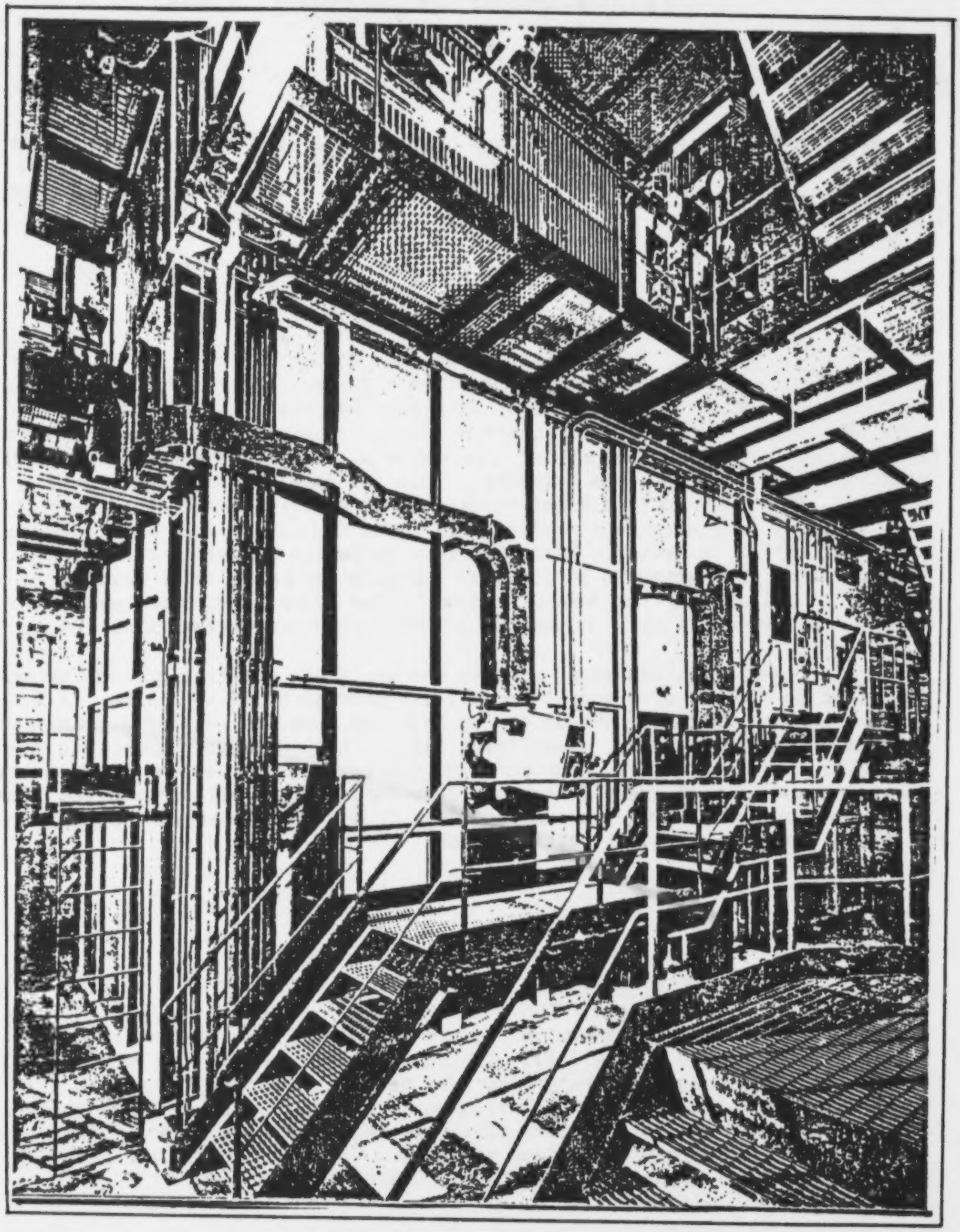


FIGURE V-1. OIL BURNER ON SIDE OF AND TOWARD REAR OF FURNACE FOR FIRING OF WASTE OIL AT BADEN-BRUGG (Courtesy of Widmer + Ernst)

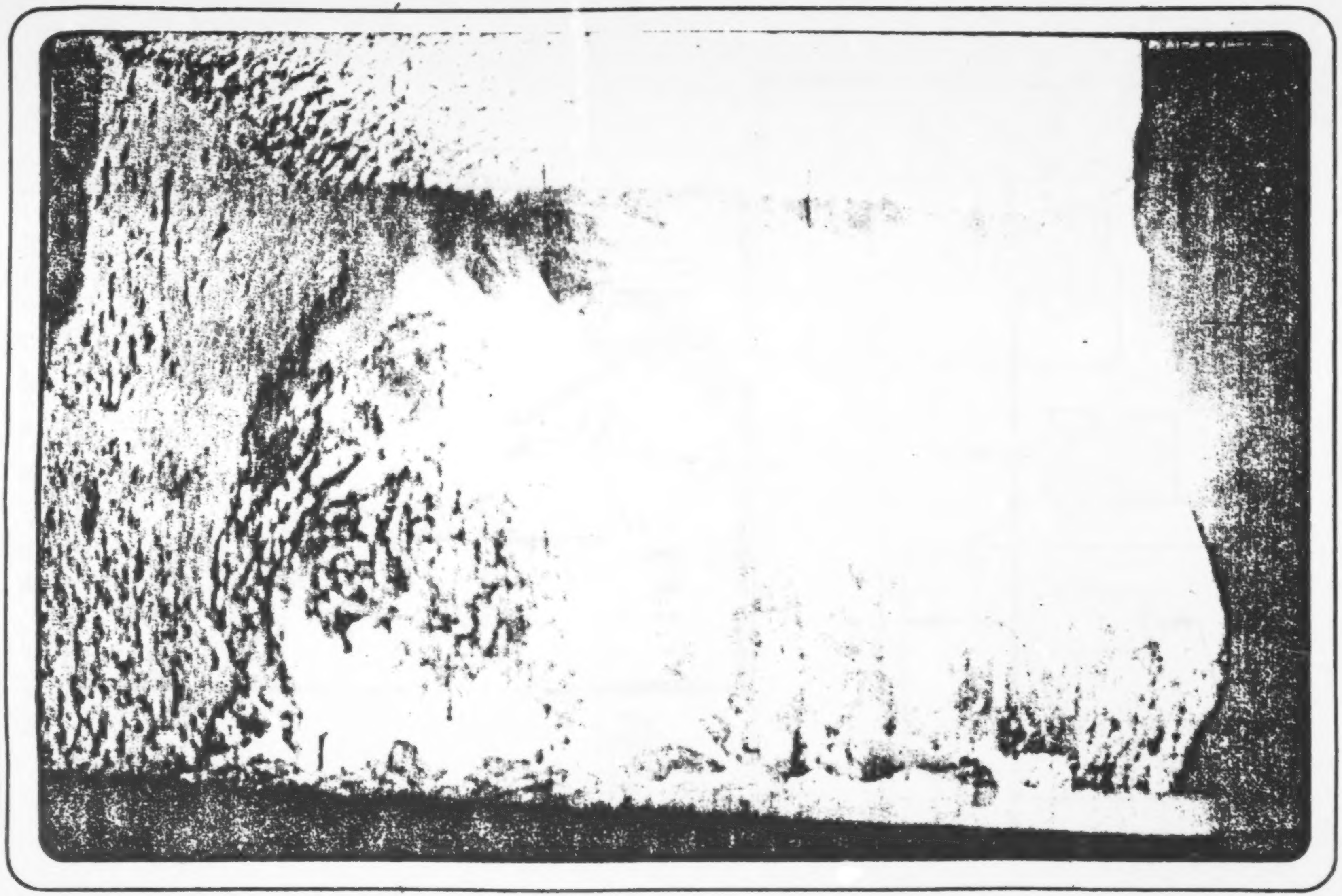
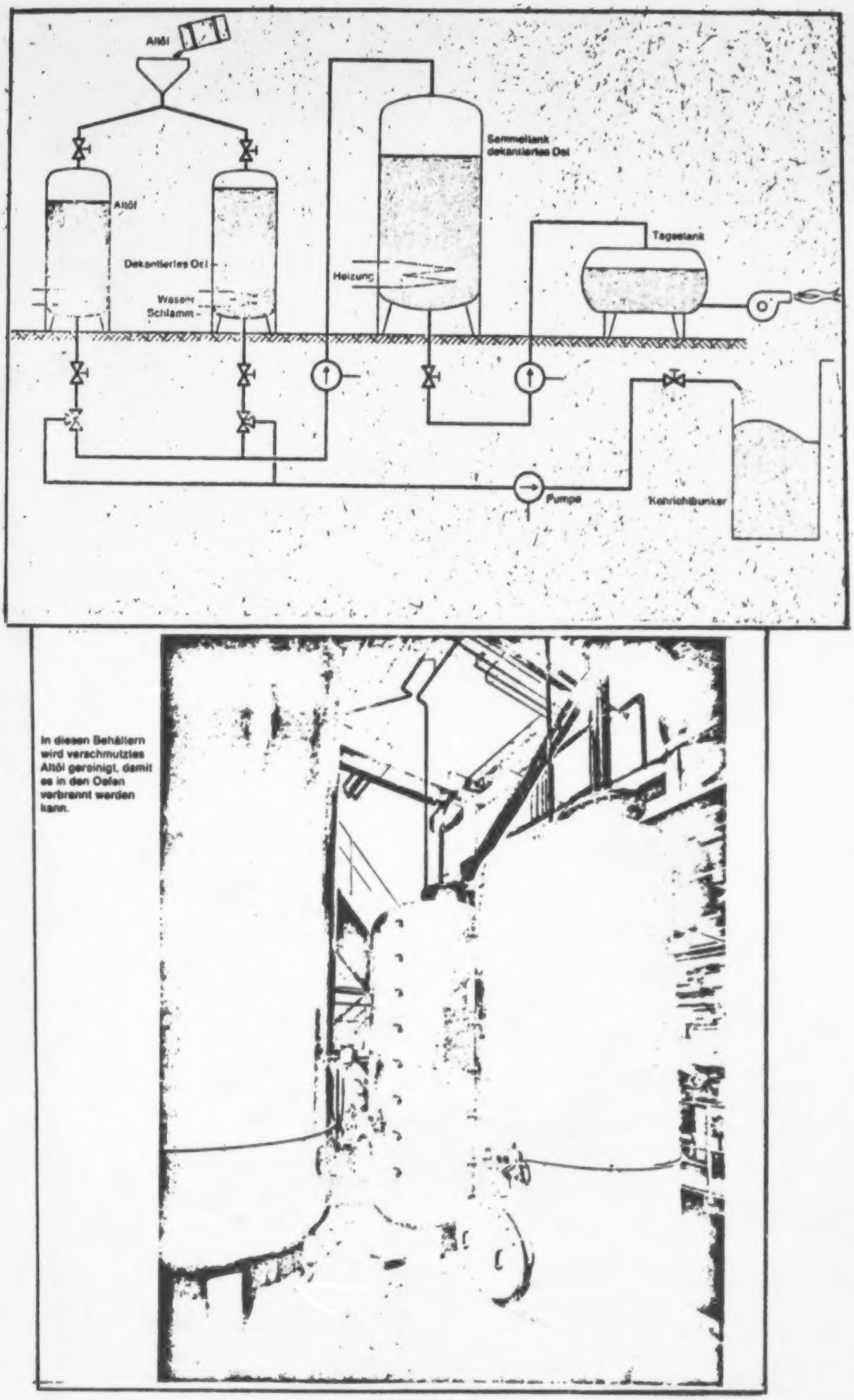


FIGURE V-2. COLOGNE, WEST GERMANY HOSPITAL WASTE INCINERATOR WITH SIDEWALL OIL BURNER (Battelle Photo)

Reproduced from best available copy.


Altöl
Sammeltank
dekantiertes Oel
Altöl
Dekantiertes Oel
Wasser
Schlamm
Heizung
Tagestank
Pumpe
Kehrichtbunker

In diesen Behältern wird verschmutztes Altöl gereinigt, damit es in den Oefen verbrannt werden kann.

FIGURE V-3. SCHEMATIC OF THE PROCESS OF WASTE OIL FIRING

Krefeld

Waste Oil. Krefeld was originally constructed with a waste oil facility but has hardly ever been used. Figure V-4 shows its location in a separate one story building to the left of the tipping pits.

The process begins with filters that remove metal turnings, debris and other coarse material. Sedimentation tanks then acts to remove free water. Finally the improved oil passes through filters before entering the storage tanks.

The cleaned oil was to have been burned by mist injection into the furnace above the sewage sludge injection nozzles in the furnace first pass about the grate.

The burners were designed to çombust 1.2 tonnes (1.3 tons) per refuse incinerator. With two lines, the combustion capacity was 58 tonnes (62 tons) per day of reprocessed waste oil at Krefeld.

The original intent was fivefold as listed below:

- Remove waste oil from the environment
- Provide energy enrichment needed to support normal sludge destruction in periods of heavy rainfall when the refuse calorific content falls (but this has not been a problem)
- Provide energy enrichment needed to destroy sludge if the dewatering system were to malfunction, i.e. if the sludge entering the furnace was 33 percent H_2O instead of the intended 10 percent H_2O (this also has not been a problem)
- Provide more energy in general
- Support national goals of energy conservation.

But as alluded to in the first paragrph, the facility is not used. Several years ago, the Federal and reginal governments initiated a policy of regionalizing industtrial waste treatment activities. A master plan was developed. Included was a provision that all waste oils collected in the Krefeld area would go to another facility.

Another factor was the alleged spirit of local waste oil generators and collectors, who apparently had more economical alternatives. For these two reasons the dormant plant may eventually be dismantled. In summary, Krefeld, in relation to the industrial waste plant, has suffered by th other plant's "capacity creation by regulation".

Hamburg:Stellinger-Moor

Methane Gas From the Sewage Treatment Plant. Formerly, methane gas from the sewage treatment plant within the same sanitary park was fed into the furnace. The practice has been discontinued. Today the gas is flared at the sewage treatment plant.

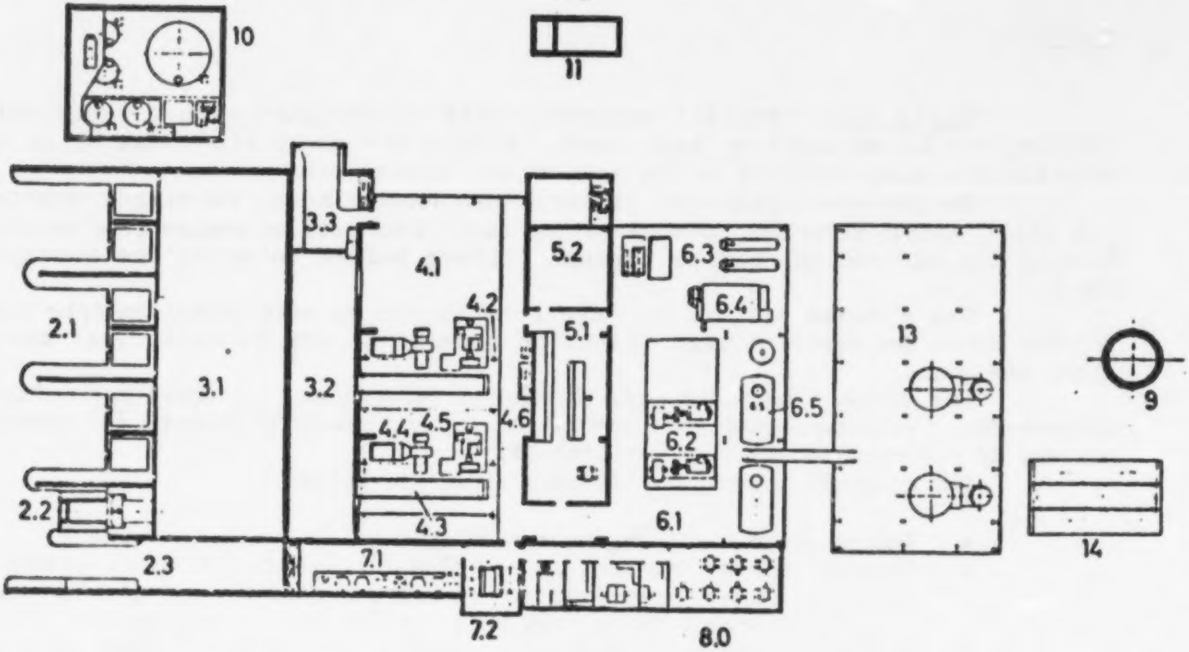

10
11
3.3
4.1
5.2
6.3
6.4
4.2
2.1
3.1
3.2
5.1
13
9
6.5
4.4
4.5
4.6
6.2
2.2
4.3
6.1
14
7.1
2.3
7.2
8.0

FIGURE V-4 . KREFELD WASTE-TO-ENERGY FACILITY: PLAN VIEW(2)

2.1	Tipping area
2.2	Bulky refuse shear
2.3	Auxillary tipping lane
3.1	Refuse bunker
3.2	Ash bunker
3.3	Ash loading area
4.1	Boiler house
4.2	Boiler pumps
4.3	Residue quencher
4.4	Primary air fan
4.5	Sludge-drying fan
4.6	Firing aisle
5.1	Washroom
5.2	Switch room
6.1	Turbine floor
6.2	Turbogenerator
6.3	Heat exchangers
6.4	Feedwater tank
7.1	Water treatment
7.2	Stairwell
8.0	Social room
9	Chimney
10	Waste oil facility
11	Cold water basin
13	Flue gas scrubbers

Number 2 Fuel Oil. The Number 2 oil fired burner port is 6 meters (20 feet) above the grate. The burner can be swung into the furnacce opening when needed.

Usually, the oil burner is used 5 to 6 hours for start up. Operators open a bypass and the ESP temperature is raised to 180°C. A cold ESP will not work well.

An unusual use is if the feed chute becomes stuck, the oil burner can be turned on to help keep the system stabilized.

Zurich:Hagenholz

Number 2 Fuel Oil, Waste Oil and Solvents. Hagenholz is equipped with two Sulzer (of Zurich) fossil fuel boilers; one for Number 2 fuel oil and another boiler for both waste oil and waste solvents. Some operating figures are shown below:

	Annual Totals	
	1974	1976
Number 2 fuel oil fired boiler #1 (operating hours)	201	182
Waste oil and solvent fired boiler #2 (operating hours)	1,486	2,099
Total (boiler - operating hours)	1,687	2,281
Number 2 fuel oil fired boiler #1 (tons of steam)	1,413	1,404
Waste oil and solvent fired boiler #2 (tons of steam)	11,244	13,192
Total (tonnes of steam produced)	12,657	14,596
Number 2 fuel oil burned (tons)	109	108
Waste oil burned (tons)	794	1,102
Waste solvents burned (tons)	71	113
Total (tonnes of material burned)	974	1,323
Waste oil collected (tonnes)	1,654	1,801

It would be incorrect to label these activities as co-firing. The refuse burning areas are not connected at all to the oil burning areas. Max Baltensperger feels very strongly that no other fuel should be fired in the same cmbustion chamber as refuse because of inevitable problems of ash deposits on boiler tubes.

The Number 2 fuel oil boiler is only used to preheat the boiler and the air preheater for the benefit of the electrostatic precipitator. The waste oil burner boiler, however, is a completely separate system devoted to waste oil destruction and energy recovery.

Reading of CO_2 and opacity (Ringleman scale) are used to control these oil burning systems. There have been corrosion problems in the steel stack of these waste oil boilers.

Figure V-5 shows the general layout of the solvent and waste oil preparation area. The waste oil is heated and decanted. The oil, water, and sludge are pulled off separately. The sludge at the bottom of the decanting tank is mixed with the municipal solid waste in the pit. The oil overflow goes to the boiler.

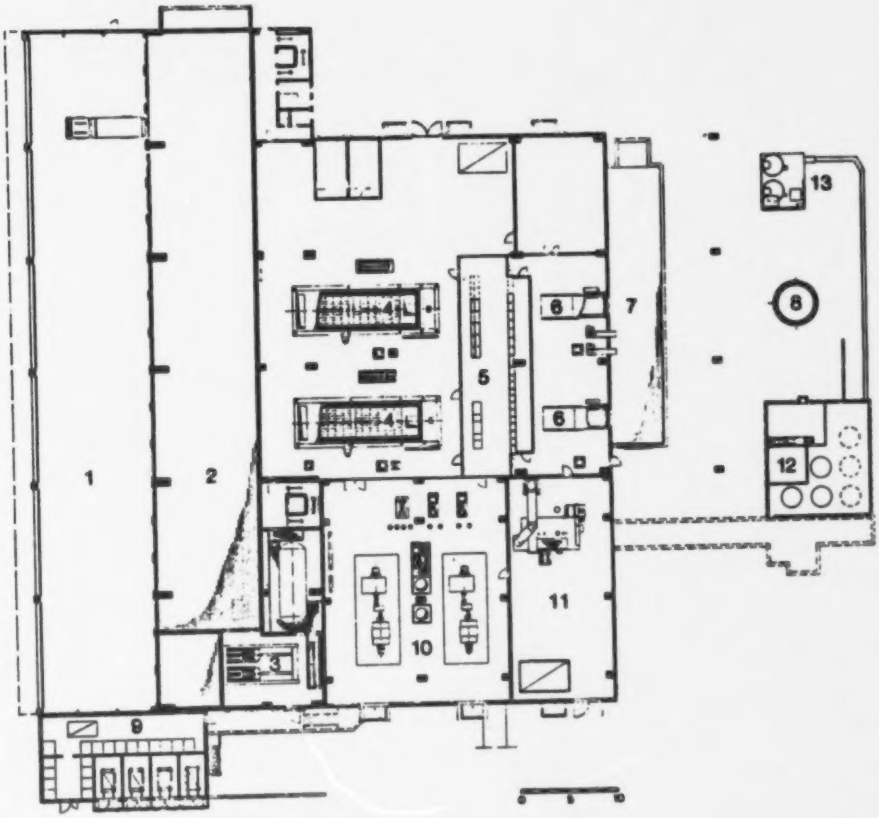
Copenhagen: Amager

Cofiring is not practiced at Amager. However, and for the record, Volund did cofire with refuse and coal in a 3-1/2 tonne/day Gentofte in 1931. The 40 year old units serving Copenhagen at Gentofte and at Fredericksburg were replaced with the units at Amager and West.

Amager does not need standby capability because its baseload steam is sent to the adjoining large electrical power and district heating plants.

Copenhagen: West

The refuse-fired hot water plant has no standby equipment and does not fire waste oil. However, here is a conventional fuel oil district heating plant adjacent. The base-load refuse-derived steam is fed into the peaking oil-fired plant prior to entering the district heating network.



Item Number	Activity
12.	Waste Oil Processing and Solvent Mixing
13.	Waste Solvent Receiving Station

(Diagram shows the first two Von Roll units but not the third Unit from Martin.)

FIGURE V-5. WASTE OIL AND SOLVENT RECEIVING, PROCESSING AND MIXING LAYOUT AT ZURICH:HAGENHOLZ

CO-DISPOSAL OF SEWAGE SLUDGE AND REFUSE

Co-Disposal, General Comments

In 1977, the Europeans were well advanced over North Americans in the combined destruction of refuse and sewage sludge within ther same system. Seven (7) such plants were visited in Europe. (See Table W-1.) Several other plants are listed as well. Of note is that each of the six major European manufacturers have a co-disposal system in operation.

Most processes involve several stages of drying as listed in Table W-2. Typically, an initial unit will convert incoming raw sewage sludge at 94-96 percent moisture to 70-80 percent moisture. At this moisture level, the sludge has a thick consistency that can lead to dramatic further moisture reductions down to 5-20 percent. The third stage of several processes is to burn the dried sludge.

From a reliability standpoint, each of the described processes does work a respectable part of the time. Unfortunately, economic data was not available for enough systems to perform any kind of economic analysis.

Co-Disposal, Comments About Specific Systems

Krefeld

VKW's third generation co-disposal technology has been constructed at Krefeld, West Germany, several miles west of Duesseldorf. The primary waste water treatment plant, see Figure W-1, is on the same property as is the refuse treatment plant. At the time of the visit in 1977, only primary undigested sludge was being piped underground to the co-disposal plant.

Figure W-2 is a schematic showing the overhead arrangements at Krefeld.

A major portion of the energy released in the two Krefeld boilers is utilized in the drying of sewage sludge from the adjacent waste water treatment plant. As indicated in the dotted area in Figure W-2 immediately east of the present settling tanks, an activated sludge treatment addition is being built. This should be on line by 1980. This may have a significant effect on the amount of energy required for sludge drying.

Figure W-3 shows the sludge handling system. The settled sludge is now pumped without further treatment to flocculating tanks where a chemical conditioner is added. Then, with a water content of about 94 percent, it is pumped to one of four centrifuges which reduce the water content to about 74 percent. The removed water is returned to the wastewater treatment plant.

The partially dewatered sludge then flows to a surge tank and thence to the large Babcock mills, one per boiler, where it is mechanically disintegrated by the high speed paddles in an atmosphere of air mixed with hot flue gas which is taken from near the top of the boiler radiation pass as shown in Figure W-4 (Item 13). The hot flue gas thus enters the mixing chamber

TABLE W-1. CO-DISPOSAL OF REFUSE AND SEWAGE SLUDGE LOCATION, SYSTEM VENDOR AND AMERICAN LICENSEE

Locations Visited	System Vendor	American Licensee	Process Type
Krefeld, West Germany	VKW	Grumman Ecosystems	Flue gas drying of sludge in Hammermill, Sludge Suspension Firing
Dieppe, France	VonRoll	Wheelabrator-Frye	LUWA Steam Thin Film Centrifugal Dryer, sludge fired with refuse on grate
Deauville, France	VonRoll	Wheelabrator-Frye	LUWA Steam Thin Film Centrifugal Dryer, sludge fired with refuse on grate
Horsens, Denmark	Bruun & Sorensen	-	Sludge Dried in Rotary Kiln, sludge is landfilled or landfarmed
Copenhagen, West Denmark	Volund	Waste Management	Wet sludge is dumped into pit and mixed with refuse prior to burning
Ingolstadt, West Germany	Widmer & Ernst	Widmer & Ernst	Twin Mixing Worm of 75% water sludge plus 10% water sludge = 35% water sludge, then flue gas drying Hammermill, sludge suspension firing over refuse
Athus, North Denmark	Brunn & Sorensen	-	
Biel, Switzerland	Dano	Dano Resource Recovery, Inc.	Refuse shredding, mix with sewage sludge in rotary kiln digesters (2-3 days), aerobicly turn twice per week outside for 4-6 months
Biel, Switzerland	Bricolari	-	Refuse shredding, mix with sewage sludge, Bricolari press (24 x 8 x 8 inch) bricks, anaerobicly store 4-5 weeks
Other Co-Disposal Systems			
Harrisburg, Pennsylvania, USA	Martin	UOP	Mix semi-dried sewage sludge in refuse pit, burn together to reduce chloride corrosion
Dordrecht, Netherlands	Martin	UOP	Flue gas from refuse burning provides heat for multiple hearth sludge furnace.
Contra Costa, Calif., USA	Envirotech	Envirotech	Shred refuse, feed refuse and sewage sludge into multiple hearth furnace (Experimental)
Ternier, Chauny, France	SOCEA	-	Suspension firing of the semi-dried sewage sludge in the hot flue gas from the MSW Incinerator. Ternier was pilot. Chauny, 1978, is full Scale.

TABLE W-2. CO-DISPOSAL UNIT OPERATION MOISTURE CONDITIONS

(Moisture of Sludge Alone or Refuse and Sludge (combined)

Unit Operation	Beginning Water %	Ending Water %
Band Press	94-96	70-80
Filter Press	94-96	45-50
Centrifuge	94-96	70-80
Mixing Sludge into Refuse Pit	94-96	20-30
Mixing Sludge into Dano Rotary Kilm for 2-3 days	94-96	?
Thin Film Dryer Using Steam from the RFSG	94-96	5-15
Rotary Kilm with Hot Flue Gas from Refuse Burning	94-96	40-50
Mixing Wet Sludge with Some 5-15% H_2O Dried Sludge	94-96	35-40
Hammermill with Hot Flue Gas from Refuse Burning	70-80	5-10
Making Bricolari Bricks Anaerobic Decomposition Over 1 Month Period	50-55	15-20
Breaking Up Bricks for Aerobic Decomposition	15-20	35-40
Aerobic Decomposition with Pipe Turning 2-3 times per wk.	?	35-40
Burning Refuse and Sludge on a Grate	25-40	0
Suspension Burning Above a Refuse Grate	5-15	0
Multiple Hearth Burning	?	0

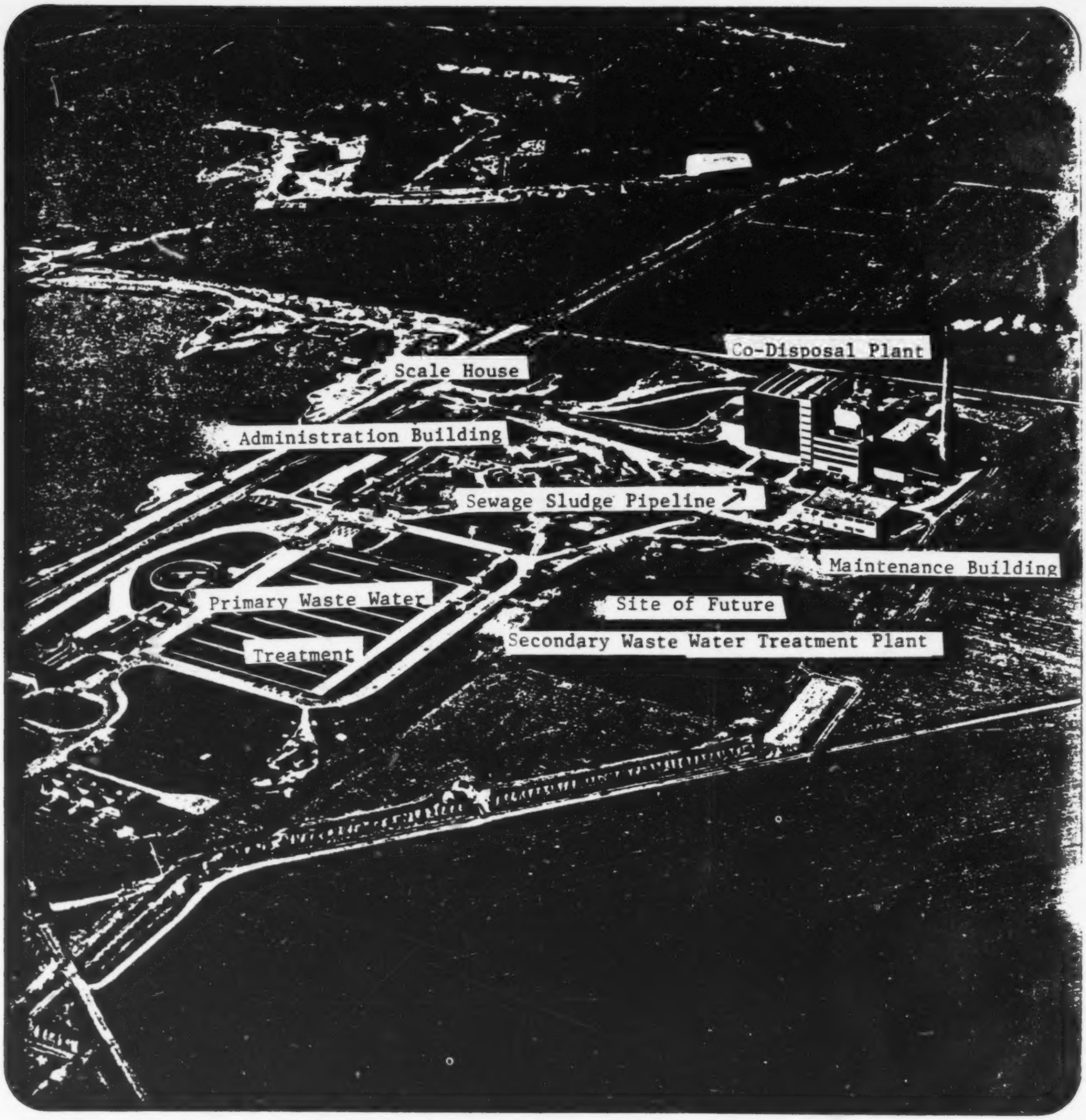

Co-Disposal Plant
Scale House
Administration Building
Sewage Sludge Pipeline
Maintenance Building
Primary Waste Water
Treatment
Site of Future
Secondary Waste Water Treatment Plant

FIGURE W-1. KREFELD WASTE PROCESSING FACILITY; WASTEWATER TREATMENT PLANT ON LEFT, REFUSE-AND SEWAGE-SLUDGE-BURNING PLANT ON RIGHT.

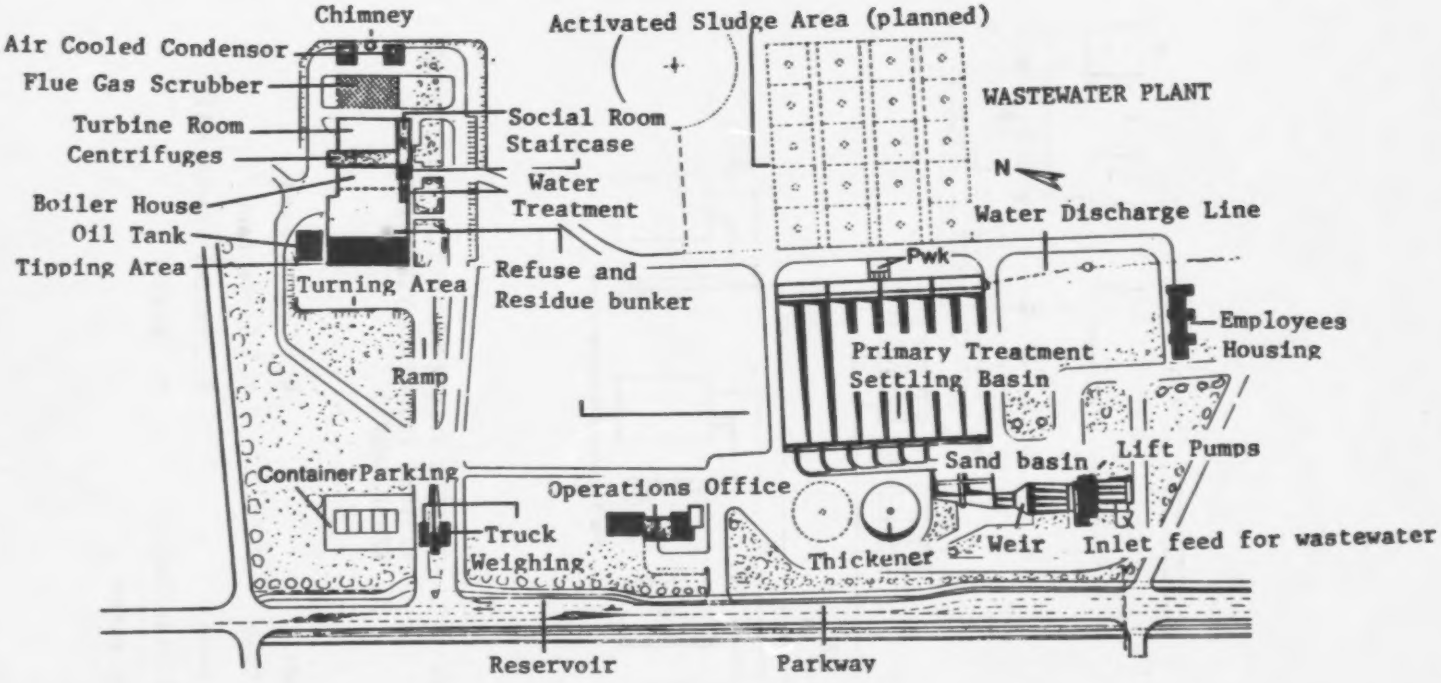

Chimney
Air Cooled Condensor
Flue Gas Scrubber
Turbine Room
Centrifuges
Boiler House
Oil Tank
Tipping Area
Turning Area
Social Room
Staircase
Water
Treatment
Refuse and
Residue bunker
Ramp
Container Parking
Truck
Weighing
Operations Office
Activated Sludge Area (planned)
WASTEWATER PLANT
N
Water Discharge Line
Pwk
Employees
Housing
Primary Treatment
Settling Basin
Sand basin
Lift Pumps
Thickener
Weir
Inlet feed for wastewater
Reservoir
Parkway

FIGURE W-2. MAP OF THE KREFELD REFUSE BURNING AND WASTEWATER PLANTS (1)

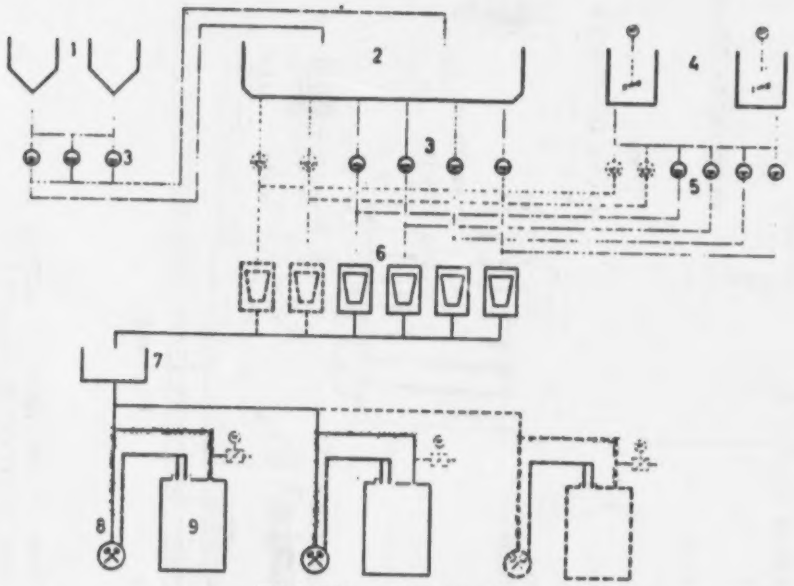


Bild 5: Schlammbehandlungsschema

FIGURE W-3. KREFELD SLUDGE-PROCESSING AND BURNING SYSTEMS (COURTESY VEREINIGTE KESSELWERKE).

1. Thickener
2. Sludge Tank
3. Sludge pump
4. Flocculating tanks
5. Metering pumps
6. Centrifuges
7. Surge tank
8. Heated hammer mill
9. Boiler

1. Tipping Floor
2. Refuse Bunker
3. Polyp Bucket
4. Hopper
5. Feeder
6. Roller Grates
7. Ash Bunker
8. Ash Crane
9. Boiler
10. Sludge Centrifuge
11. Sludge Hopper
12. Sludge Hammermill
13. Hot Flue Gas Takeoff for Sludge Mixing Chamber
14. Dried Sludge Entrance Port to Furnace
15. Control Room
16. Turbogenerator
17. Machine Room Crane
18. Feed Water Tank
19. Electrostatic Precipitator
20. Induced Draft Fan
21. Flue Gas Scrubber
22. Stack

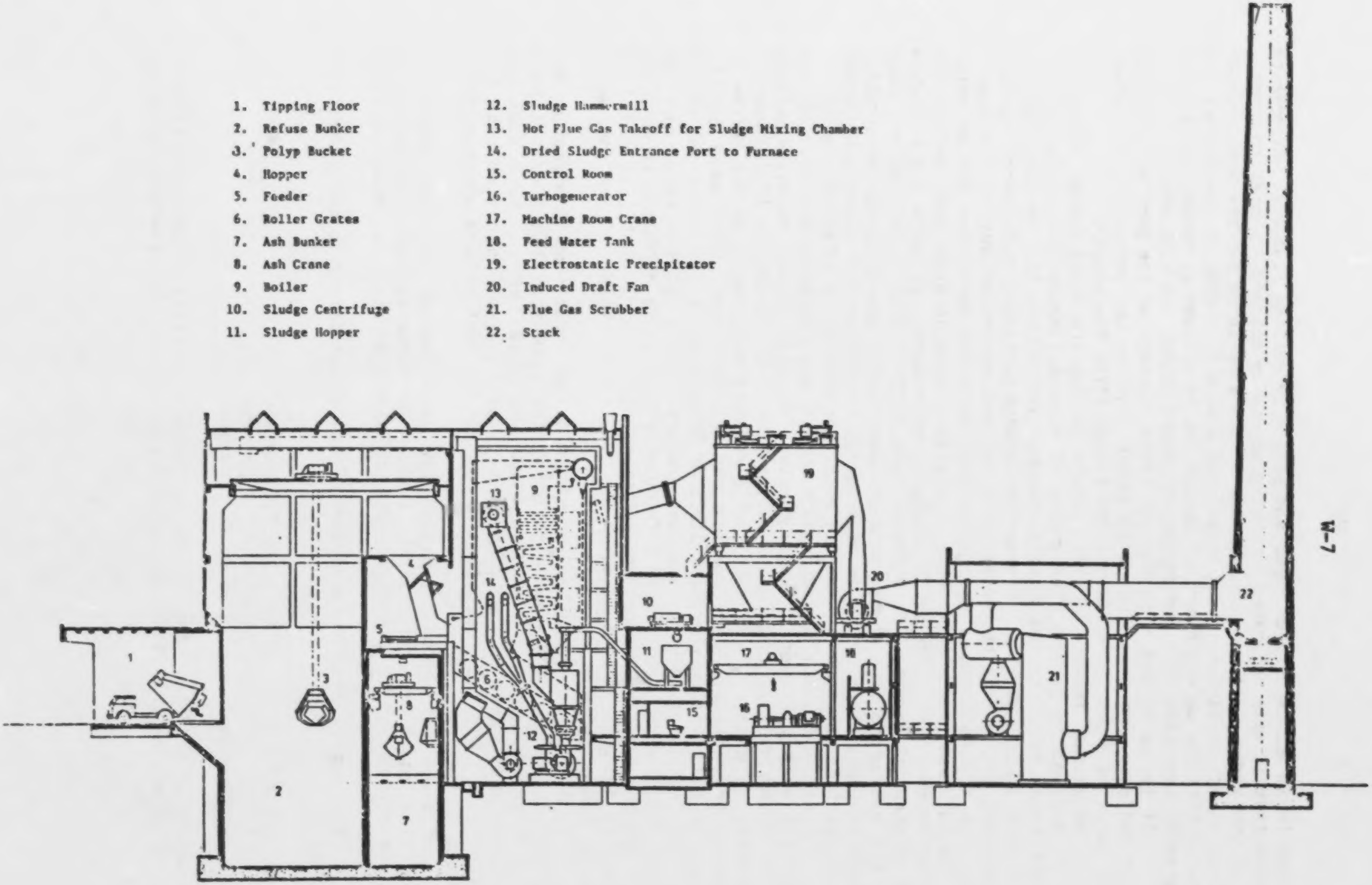


FIGURE W-4. CROSS-SECTIONAL VIEW OF KREFELD PLANT(1) conveyed in an atmosphere of vapor and partially cooling flue gas. Experience has shown that if this saturated conveying stream is allowed to cool too much, some of the vapor will be recondensed on the very large surface available on the fine, sludge particles. Long experience with mill drying of brown coal has indicated that the moisture content should not be allowed to become too low, as this greatly increases fire and explosion hazard within the mill system.

It is estimated that the moisture content of the particles leaving the mill and entering the furnace is about five to ten percent. The lower heating value is about 430 KCAL/kg (1800 KJ/kg) (7740 Btu/pound).

An unusual feature of this furnace is that the dried sewage sludge is fired in suspension in hot flue gases at a point (labeled #14 in Figure W-4) near the lower end ofthe radiation chamber and within the section that is coated with silicon carbide. Because the sludge particles still carry moisture (10 percent) and because the moisture having been vaporized out of the sludge is still in the hammermill exit gas, when both the particles and the vapor enter the hot radiation chamber they will absorb considerable heat before the paricles become heated to their ignition temperature. At point #13 in Figure W-4, a substantial amount, 2.7 to 3.9 Nm^3/sec (5715 to 8256 scfm), of hot flue gases are extracted from the furnace and sent to the sewage sludge hammermill. For these reasons, there is not as much energy available for steam generation as in straight refuse burning, and the radiation chamber is relatively small.

Figure W-5 shows the estimated conditions entering and leaving the drying mill as a function of drying rate. At full design rate,the furnace burns 12 tonnes/hr (13.2 tons/hr) of refuse plus 6.43 tonnes/hr (7.1 tons/hr) of dewatered sludge. If, because of a reduced heat value in the refuse or because of an extra moisture load in the sludge, the first pass outlet temperature falls below the legal limit of 800 C (1472 F), supplemental oil is fired automatically to maintain that temperature. No. 6 oil has been used for this purpose, but it is used so infrequently that it is difficult to keep the hot oil system in reliable condition. Accordingly, No. 2 distillate will be used in the future. As discussed in the fuel oil and waste oil section, waste oil can no longer be used.

Table W-3 shows the drying system design conditions as affecting the estimated dust loading of the gases entering the electrostatic precipitator. Three different levels of refuse heat are considered. Note that the "effective" grate area shown is 48.16 m_2 (518 ft_2) as contrasted with the estimated 35.7 (383 ft_2) used in the section on heat release where only the equivalent flat surface is considered.

Figure W-6 shows the calculated dust load of the flue gases for various "flow rates" of ash across the grate. The three calculation points on the curve correspond to the conditions in Columns marked 1, 2, and 3 in Table W-3.

The approximate composition of the sludge coming to the centrifuges at Krefeld is:

Dry solids	6.5 to 7.0 percent
Ash	2.8 to 3.2 percent
Ash/solids	40.0 to 45 percent

If the sludge is held too long in the thickener, digestion causes a loss of volatiles which affects its burning charateristics. Mr. Koerbel, the plant

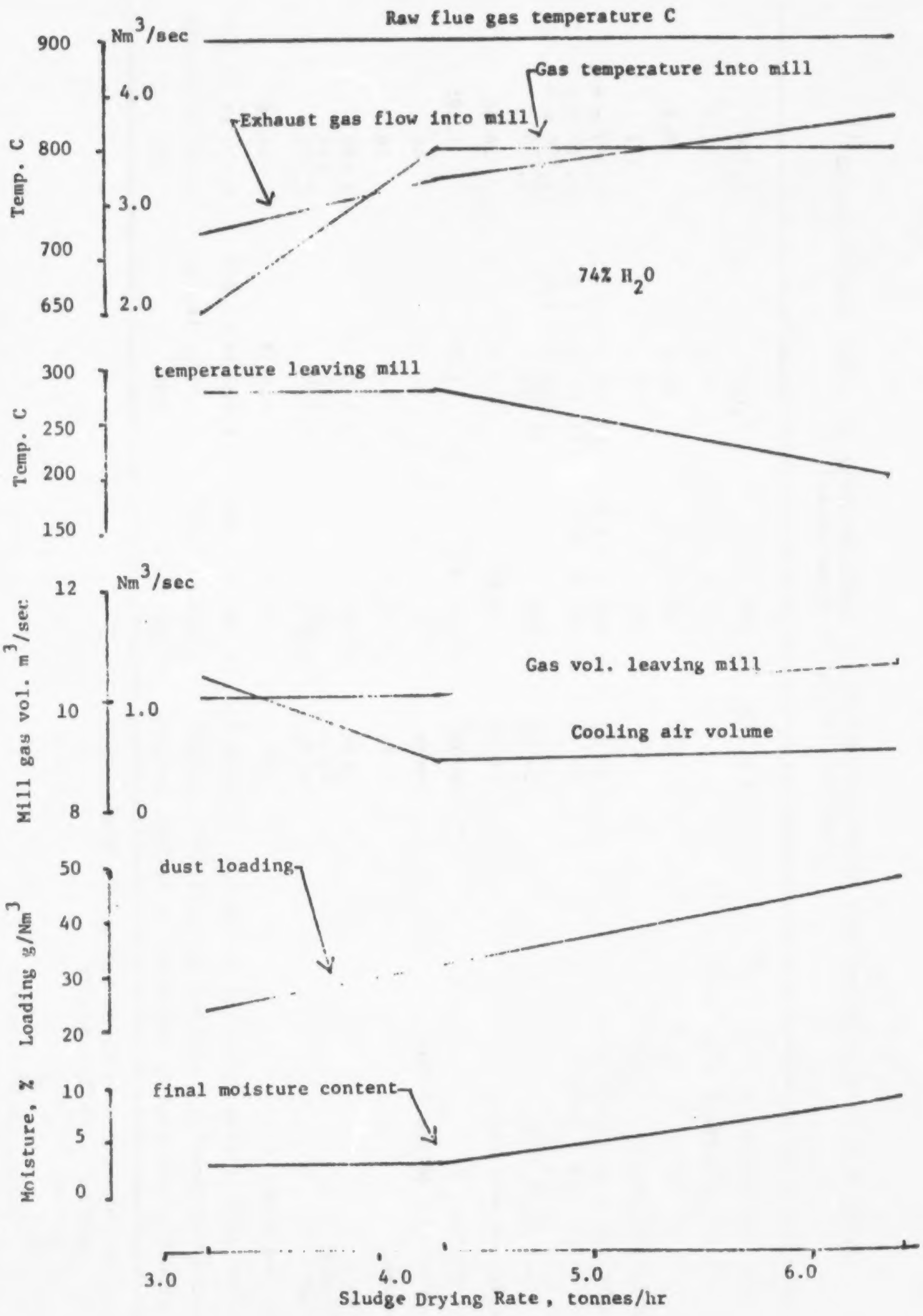


FIGURE W-5. CALCULATED DRYING MILL CONDITIONS AS A FUNCTION OF SLUDGE DRYING RATE (Courtesy Vereinigte Kesselwerke)

TABLE W-3. SLUDGE DRYING MILL DESIGN CONDITIONS FOR WASTE OF THREE (3) LOWER HEATING VALUES(1)

(Courtesy Vereinigte Kesselwerke)

Refuse Lower Heating Value	Kcal/Kg	2,500	1,600	1,000
CO_2 Before Electrostatic Precipitator	%	11.5	11.5	11.5
CO_2 Max	%	19.5	19.5	19.5
Flue Gas Temperature	°C	250	212	192
Flue Gas Volume from Refuse	Nm^3/h	64,100 n = 1.7	45,200 n = 1.7	31,900 n = 1.7
Flue Gas Volume from Sludge	Nm^3/h	12,300 n - 1.0	12,300 n - 1.0	12,300 n = 1.0
Flue Gas Volume from Oil	Nm^3/h	--	5,200 n = 1.02	15,100 n = 1.02
Total Flue Gas Volume	Nm^3/h	76,400	62,700	59,800
Flue Gas Volume per Second	m^3/s	40.65	30.94	28.06
Flue Gas Density	Kg/Nm^3	1.265	1.23	1.195
Flue Gas Pressure Before Filter	mmWs	60	52	46
Ash in Waste	%	16.5	24	29
Ash in Waste	Kg/h	1,980	2,880	3,480
Ash in Sludge	Kg/h	690	690	690
Total Ash	Kg/h	2,670	3,570	4,170
Grate Surface Area	m^2	48.16	48.16	48.16
Raw Flue Gas Dust Loading Corrected to 10% CO_2	mg/Nm^3	4,200 to 8,600	6,400 to 12,800	8,600 to 17,400
Raw Flue Gas Dust Loading Corrected to 11.5% CO_2	mg/Nm^3	4,820 to 9,900	7,360 to 14,720	9,900 to 20,000
Cleaned Flue Gas Dust Loading Corrected to 7% CO_2	mg/Nm^3	100	100	100

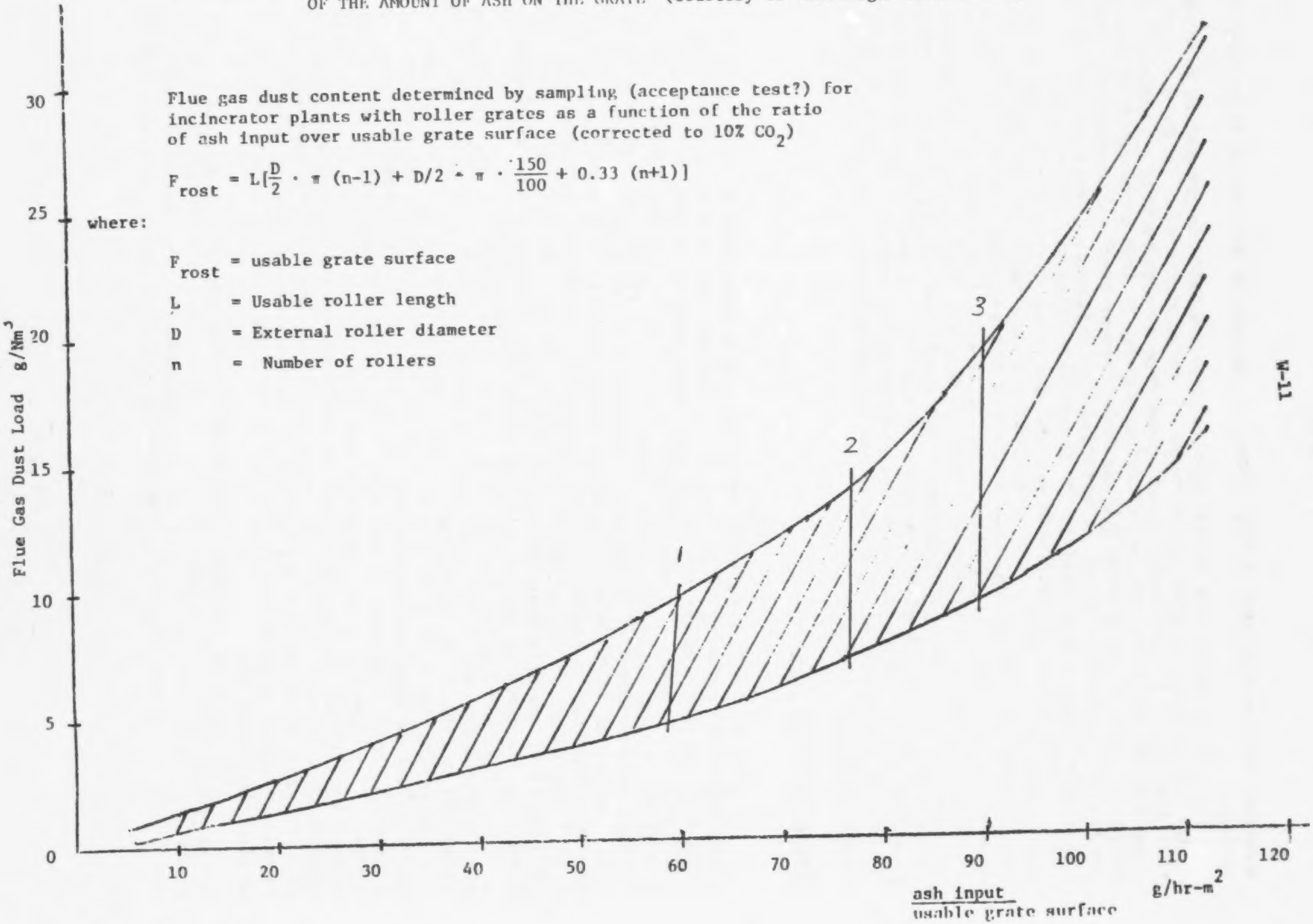
(1) In all columns a common input tonnage is assumed to be

Refuse	12.00	tonne/hr
Sludge	6.43	
Oil	1.26	
Total	19.69	tonne/hr

(2) Calculated for a barometer reading is 760 mm Hg (760 mm Hg) [29.92 in Hg]

Is "n" the excess air ratio?

FIGURE W-6. CALCULATED DUST LOAD OF THE FLUE GAS AS A FUNCTION OF THE AMOUNT OF ASH ON THE GRATE (Courtesy of Vereinigte Kesselwerke)



Flue gas dust content determined by sampling (acceptance test?) for incinerator plants with roller grates as a function of the ratio of ash input over usable grate surface (corrected to 10% CO_2)

$$F_{rost} = L[\frac{D}{2} \cdot \pi (n-1) + D/2 \cdot \pi \cdot \frac{150}{100} + 0.33 (n+1)]$$

where:

F_{rost} = usable grate surface

L = Usable roller length

D = External roller diameter

n = Number of rollers

manager, emphasized that a key element in successful processing is to keep it moving.

At present, the quantity of sludge available is greater in relation to the refuse quantity than would normally be encountered. It is estimated that the sludge to the Krefeld plant comes from an area serving a population of about 600,000 while the 400 tons of refuse per day is from a populatin of about 300,000. Some local plants such as Bayer process their own wastewater. When the Krefeld wastewater plant is modified for secondary treatment, existing regulations covering pre-treatment of industrial wastes will be enforced.

The sludge drying system was not operating during either day of our visit, May 20, 23, 1977, and data could not be released on the drying system performance because accceptance tests had not yet been run on the plant. However, a published design heat balance is available from an article in VGB Kraftswerkstechnic. A subsequent call to Grumman Ecosystems, the American licensee for VKW, revealed that the sludge system are working very well. There had been a modification after the Battelle visit to improve the sludge handling from the hopper (under the centrifuge) to the mixing chamber. The sludge which had been agglomerating along the way, now passes evenly and enters the mixing chamber much more evenly.

Dieppp (and Deauville)

This confiring system patented world-wide by Von Roll for steam-drying and cofiring sewage sludge with refuse was guaranteed at Dieppe to handle 75 percent refuse and 25 percent dried sludge (by weight). At Dieppe, there are two vertical LUWA dryers about 0.6 m (1.9 ft) inside diameter having a nominal drying capacity of 900 liters/hr (238 gal/hr) of digested sludge having a water content of 92 percent. At Deauville (50 miles away), there is only one larger LUWA dryer having a nominal capacity of 1,100 liters/hr (271 gal/hr). Normally it operates at 900 liters/hr, 24-hours/day in the summer and 4 to 6 hours/day in the winter. Evidently, for the new Deauville plant, the reliability of the LUWA dryer was deemed such that redundancy was unnecessary. Dieppe was the first to use the LUWA dryer for sewage sludge.

Figure W-7 shows the two LUWA dryers. The inside of the dryer is a smooth stainless steel cylinder having a surface of 5.3 m_2 (57 ft_2) heated to about 180 C (356 F) by saturated steam. See Figure W-8. The sludge is delivered to the dryers by a dosing pump which sprays it against the hot surface which is rapidly scraped clean by vertical rotating blades attached to a central shaft rotating at 250 rpm. Centrifugal force keeps the boiling sludge against the hot steel surface as the blades force it to rotate. Gravity causes the drying sludge particles to drift downward along the steel heating surface. The product falling from the bottom of the dryer onto a belt conveyor is partially dried sludge agglomerations having 40 to 45 percent moisture. A television camera sighted on the conveyor enables the control room operator to monitor the sludge blow.

The conveyor delivers the clumps (seldom over 2") to a chute leading to the refuse hopper. To eliminate dryer exhaust odor, the wet vapor from the dryers is fed to the upper part of the furnaces. At the Deauville plant, to avoid having droplets returned to the furnace with the vapors, a steam-heated

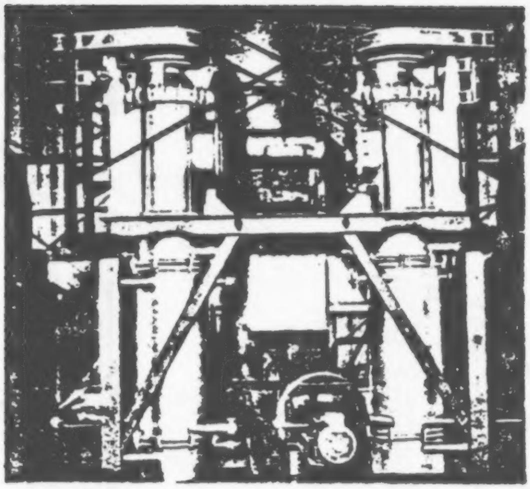


FIGURE W-7. TOP OF TWO LUWA SLUDGE DRYERS AT DIEPPE (COURTESY OF VON ROLL, LTD.)

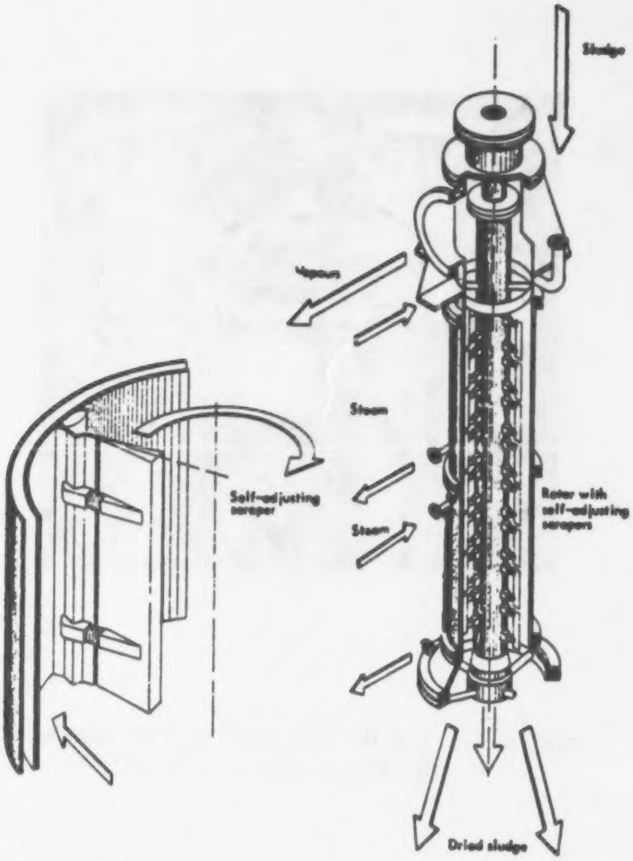

Sludge
Vapours
Steam
Self-adjusting scraper
Rotor with self-adjusting scrapers
Steam
Dried sludge

FIGURE W-8. CUTAWAY DRAWINGS SHOWING PRINCIPLE OF LUWA DRYER (COURTESY OF VON ROLL, LTD.)

vapor reheater is used to dry the vapor before it is injected into the furnace. At Dieppe, a radioactive sludge feed indicator was installed but it is no longer used.

An unkown amount of exccess steam is sent to a river water-cooled condenser, the condensate from which is returned to the boiler.

Krings has prepared Table W-4 in which he estimated the amount of excess heat generated by the Dieppe plant under three different rates of operation. In that calculation, no explicit allowance was made for the heat value of the partially dried sludge. That is a realistic policy for sludge having a moisture content of 40 percent or more. For although the partially dried sludge does release some heat when burned, the amount released from the sludge is not a large proportion of the total liberated in the furnaces.

Table W-5, from Eberhardt, shows the heat value of various raw sludges. Figure W-9 from Eberhardt shows the relation of heat value to ash and combustible content. From this, it is evident that although the combustible portion of dry sludge may have a lower heat value of up to 10,000 Btu/lb (5,555 Kcal/kg), it is usually so diluted by ash and water that the net heat value is low.

In 1973, test were run at Dieppe, one result of which was Figure W-10 by Krings showing the efficiency of the LUWA dryers. Three of the lowest points near the center of the figure show the results from fresh, undigested sludge. This indicates that this digested sludge was more readily dried than the raw sludge.

Some difficulty is experienced at both plants when fibrous materials clog the dryer feeding system.

The operating group, Thermical-INOR, is required by its contract with the city of Dieppe to gather and submit performance data for the refuse and wastewater plants. Tables W-6 and W-7 show the refuse plant results for the year 1976. The total two-furnace operating time of 6,228 hours is 35 percent based on a total of two time is 45 percent. As indicated early in this report, the Dieppe plant was sized in anticipation of considerable growth in load.

Table W-8 summarizes the refuse plant operation over the 5 years, 1972-1976. Load and performance have been quite steady over the period.

Horsens

The Horsens wastewater treatment plant serving a population of 38,000 was built adjacent to the refuse burning plant so that the difficult problem of sewage sludge disposal could be assisted by partial drying of the sludge.

Figure W-11 is a schematic view of the plant in which the rotary kiln type of dryer is emphasized.

Typical analyses by the city laboratory of sludge pumped to the dryer are as follows:

	May 24, 1974	Sept. 5, 1977
pH	5.52	7.2
Dry Solids, percent	13.3	6.5
Combustible, percent of DS	66.7	46.7

The sludge is coagulated at the wastewater plant by means of a polyelectrolite and is then centrifuged before being pumped to the dryer.

TABLE W-4. RESULTS OF CALCULATION BY KRINGS OF HEAT BALANCE FOR DIEPPE PLANT

		One Furnace Lower Heat Value, 1,200 kcal/kg	One Furnace Lower Heat Value, Maximum, 2,000 kcal/kg	Two Furnaces Lower Heat Value, Maximum, 2,000 kcal/kg
Net Heat Available From Combustion	Gcal/day	35.5	68.7	171.2
Total Heat Requirement for Sludge Drying	Gcal/day	22.0	22.0	65.0
Excess Heat to Dump Condenser	Gcal/day	13.5	46.7	106.2
Equivalent Population	People	Approximately 50,000		Approximately 125,000

Source: Krings, J., French Experience With Facilities for Combined Processing of Municipal Refuse and Sludge, Proceedings, CRE-Conference on Conversion of Refuse to Energy, Montreaux, Switzerland, November 3-5, 1975.

TABLE W-5. APPROXIMATE COMPOSITION AND LOWER HEAT VALUE OF SOME TYPICAL RAW SEWAGE SLUDGES ACCORDING TO EBERHARDT

	Ash, Percent	Water, Percent	Combustible Matter, Percent	Volatile Matter, Percent	Lower Heat Value	
					Btu/lb	Kcal/kg
Ruhr Sludge	48.2	40.0	11.8	--	1,050	583
Dry	80.3	--	19.7	14.6	2,480	1,367
Berne Sludge	21.7	55.0	23.3	--	2,770	1,537
Dry	48.2	--	51.8	24.8	6,300	3,497
Emscher Sludge	29.0	44.5	26.5	--	3,300	1,832
Dry	52.3	--	47.7	19.3	6,770	3,757
Saar Sludge	33.6	40.0	26.4	--	3,400	1,887
Dry	56.0	--	44.0	17.5	6,400	3,552
Niers Sludge	2.5	93.0	4.5	--	--	--
Dry	36.0	--	64.0	--	6,280	3,485

Source: Eberhardt, H., European Practice in Refuse and Sewage Sludge Disposal by Incineration, Proceedings, 1966 National Incinerator Conference, ASME, New York, May, 1966, pp 124-143.

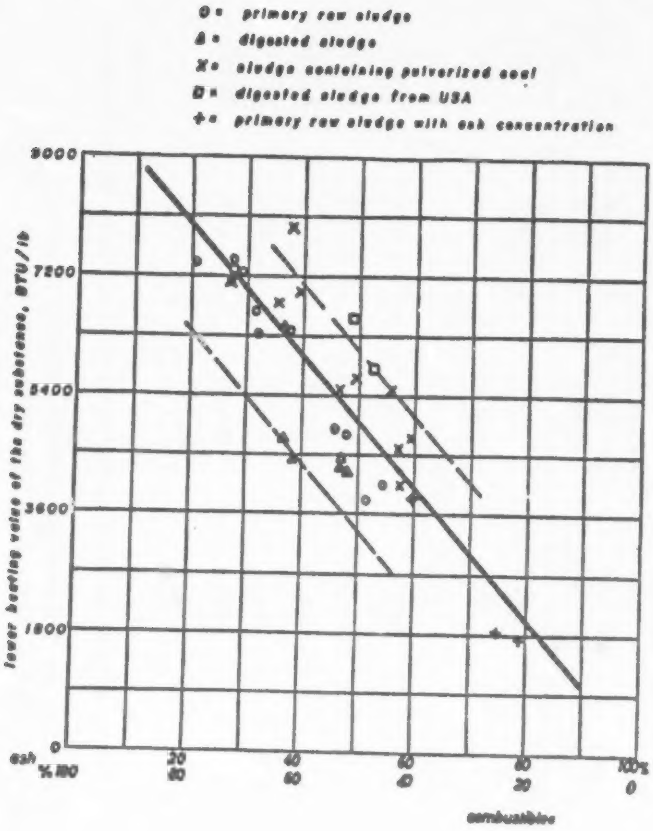


FIGURE W-9. PLOT BY EBERHARDT OF RELATION OF COMBUSTIBLE AND ASH CONTENT OF DRY SEWAGE SLUDGE TO ITS LOWER HEAT VALUE

Source: Eberhardt, H., European Practice in Refuse and Sewage Sludge Disposal by Incineration, Proceedings, 1966 National Incinerator Conference, ASME, New York, May, 1966, pp 124-143.

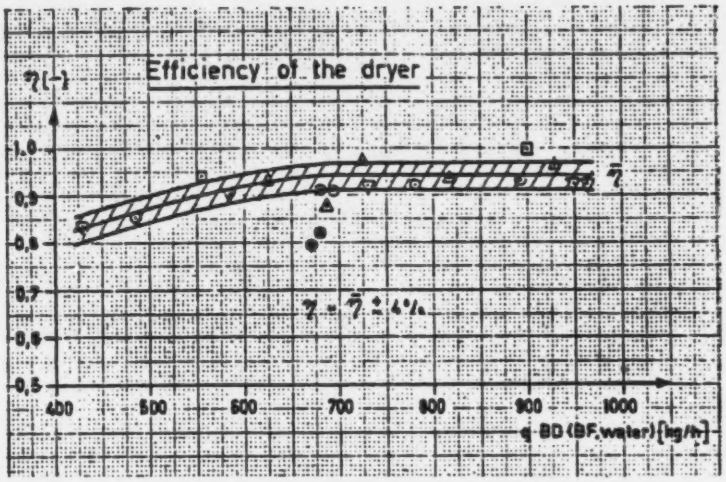


FIGURE W-10. KRINGS RESULTS OF TESTS IN 1973 AT DIEPPE ON THE EFFECT OF TYPE OF SLUDGE AND SLUDGE FEED RATE ON THE EFFICIENCY OF THE LUWA THIN-FILM DRYER

Source: Krings, J., French Experience with Facilities for Combined Processing of Municipal Refuse and Sludge, Proceedings, CRE-Conference on Conversion of Refuse to Energy, Montreaux Switzerland, November 3-5, 1975.

▽ Water

● Fresh Sludge - 97 Percent Water

⊖ Digested Sludge - 98 Percent Water

▲ Digested Sludge - 95 Percent Water

⊡ Digested Sludge - 92 Percent Water

TABLE W-6. SUMMARY FOR 1976 OF REFUSE-SLUDGE BURNING PLANT OPERATION AT DIEPPE. TABULATION PREPARED BY PLANT OPERATORS, THERMICAL-INOR, IN FULFILLMENT OF THEIR OPERATING CONTRACT WITH THE CITY

	January	February	March	April	May	June	July	August	September	October	November	December	Total
Source and Amount of Refuse, kg													
Dieppe	826,350	751,250	879,950	873,300	893,000	889,950	943,800	914,150	839,200	864,100	855,150	826,650	10,357,050
Neuville les Dieppe	331,700	304,300	365,500	354,100	359,050	351,150	339,550	327,750	353,350	357,400	375,500	352,650	4,172,000
Rouxmesnil	21,400	17,850	22,850	25,950	24,100	20,400	24,450	21,250	22,500	25,850	26,300	25,550	278,450
Manehouville	1,200	1,300	1,400	800	1,100	2,150	1,200	1,600	1,400	1,200	1,150	1,850	16,350
Martigny	2,600	3,050	2,600	2,700	3,000	2,700	2,250	3,350	3,100	3,150	3,000	2,550	34,050
Crosville	1,100	1,400	900	1,200	1,050	1,100	1,250	2,050	1,500	900	1,450	900	14,800
La Chaussee	750	1,200	1,100	950	1,150	900	950	1,400	1,150	1,500	1,200	1,000	13,250
La Chapelle du Bourgay	400	500	500	550	700	400	450	700	650	500	550	500	6,400
Industrial, Commercial	156,700	149,750	144,700	123,800	123,300	134,400	125,850	62,350	127,250	112,800	116,850	158,600	1,536,350
TOTAL REFUSE, kg	1,342,200	1,230,600	1,419,500	1,383,350	1,406,450	1,403,150	1,439,750	1,334,800	1,350,100	1,367,400	1,381,150	1,370,250	16,428,700
Volume of Digested Sludge Dried and Burned, m^3	315	405	345	395	390	345	345	460	415	490	350	345	4,600
Production of Clinker, kg	646,050	568,550	612,350	550,350	488,650	677,500	608,350	582,600	568,050	594,050	636,100	617,550	7,149,750
Electrical Energy Consumed, kw	62,700	54,700	54,600	58,700	55,300	76,000	73,200	60,200	55,200	61,000	59,400	65,900	736,900
Period of Furnace Operation													
Furnace 1, hours	191	209	376	271	0	300	293	163	310	319	344	173	2,949
Furnace 2, hours	295	229	112	176	443	402	305	351	160	227	211	368	3,279
Total Furnace Operation	486	438	488	447	443	702	598	514	470	546	555	541	6,228

TABLE W-7. DIEPPE WASTEWATER PLANT SUMMARY FOR 1976. TABULATION PREPARED BY THERMICAL-INOR, IN FULFILLMENT OF THEIR OPERATING CONTRACT WITH THE CITY

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Wastewater treated, m^3	133,630	136,750	148,480	139,320	153,260	152,350	150,960	132,420	162,550	139,290	132,280	158,900	1,740,190
Digested sludge produced, m^3 (approx. 92% water)	315	405	345	395	390	345	345	460	415	490	350	345	4,600
Gas produced, m^3 (approx. 65% CH_4)	11,737	13,925	15,967	14,810	14,535	14,391	12,366	11,040	13,362	12,916	11,381	11,518	157,948
Chlorine used, kg	75	75	75	75	75	75	75	75	75	75	75	75	900
Electricity consumed, kWh	44,700	42,100	45,700	44,300	42,600	41,500	41,800	38,700	42.400	44,800	43,500	45,900	518,000

TABLE W-8. ANNUAL REFUSE INCINERATOR OPERATING RESULTS FOR DIEPPE - 1972-1976 (COURTESY VON ROLL, LTD.)

		1972	1973	1974	1975	1976
Combustion						
Refuse	tonnes	17,291	18,885	19,185	18,446	16,428
Clinker and flyash	tonnes	6,702	7,265	7,359	7,298	7,149
Operating Hours						
Furnace 1	h	3,423	3,281	4,083	3,325	2,949
Furnace 2	h	3,985	3,353	4,343	3,153	3,279
Power Consumption x 1000	kWh	733	779	818	711	737
Power Consumption/t Refuse	kWh/t	42.42	41.25	42.62	38.54	44.85
Total Water Consumption	m^3	941,538	1,079,968	910,061	827,396	--
City Water	m^3	43,298	68,578	51,441	53,246	--
Industrial Water	m^3	898,240	1,011,390	858,620	774,150	--
Water Consumption/t Refuse	m^3/t	54.45	57.19	47.44	44.86	--

Note: To convert metric tonnes to short tons multiply by 1.1
To convert cubic meters to gallons multiply by 264.2

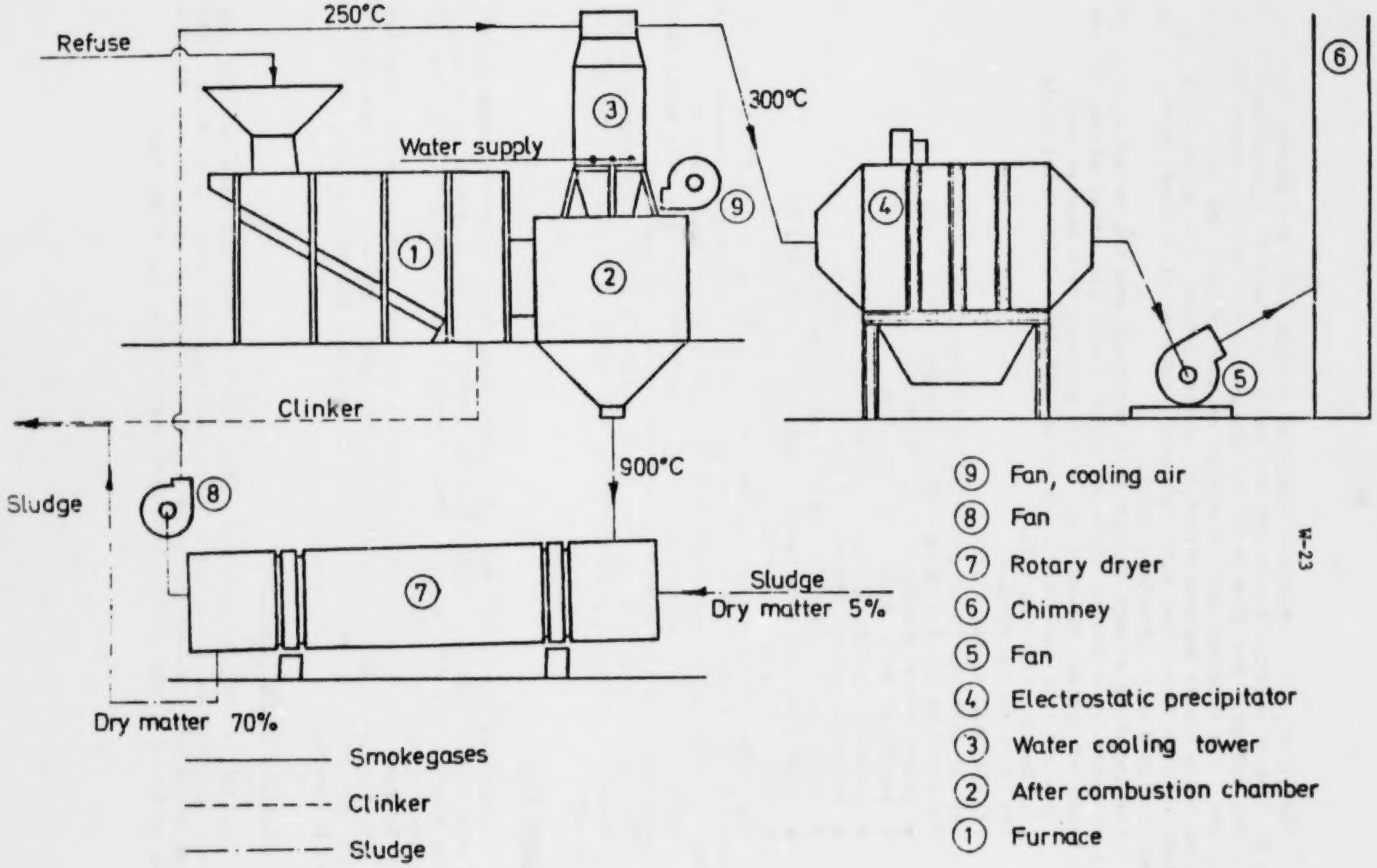

250°C
Refuse
300°C
Water supply
③
⑨
④
⑥
①
②
⑤
Clinker
900°C
Sludge
⑧
⑦
Sludge
Dry matter 5%
Dry matter 70%
Smokegases
Clinker
Sludge
⑨ Fan, cooling air
⑧ Fan
⑦ Rotary dryer
⑥ Chimney
⑤ Fan
④ Electrostatic precipitator
③ Water cooling tower
② After combustion chamber
① Furnace

FIGURE W-11. DIAGRAM OF HORSENS REFUSE-BURNING AND SLUDGE-DRYING PLANT (COURTESY OF BRUUN AND SORENSEN)

The rotary kiln receives digested sludge from the sewage plant and reduces it from it nominal 5 percent dry solids content to approximately 70 percent dry solids. Hot flue gases and sludge are fed into the rotary kiln at the same end. The rotating part is carried on two rollers for axial control. A special scoop system ensures effective contact between flue gases and sludge. The rotary kiln is insulated with rockwool, covered with steel plate. The inlet end is lined with refractory brick.

The incoming sludge is fed by a monopump and the dried sludge is emptied by means of a spiral conveyor which leads the dried sludge to the clinker transport system, directly out of the building to a storage area.

There are then four possibilities for displsal of the dried sludge:

(1) Deposit with the clinker
(2) Burn in the furnace
(3) Utilize as fertilizer
(4) At present, it is deposited in the landfill.

The kiln has the following specifications:

- Rotary dryer diameter: 2.5 m (8.2 ft)
- Length of dryer drum: 16 m (52.5 ft)
- Incoming sludge: Approx. 5 percent dry solids
- Outgoing matter: Approx. 70 percent dry solids
- Capacity: 5 m^3/hr (22 gpm) of wet sewage sludge
- Inlet flue gas temperature: Approx. 900 C (1,652 F)
- Outlet flue gas temperature: Approx. 225 C (437 F).

The sludge is reduced from approximately 5,000 kg/hr (11,000 lb/hr) to approximately 360 kg/hr (792 lb/hr) by going through the drying process. This represents an evaporation heat rate of about 2.70 Gcal/hr (10.2 M Btu/hr).

Some difficulty was encountered with odor from the kiln until high enough operating temperatures were assured on startup and shutdown.

The recent retrofit of the furnace with a boiler (described in the boiler chapter) to produce district heating hot water will change some of the above numbers.

Copenhagen: West

While touring either the Copenhagen: West facility or the Hague plant, these researchers observed a sewage sludge tanker truck disgourging material into the pit over the refuse. The crane operator would then distribute the wet refuse over the other material.

Because the furnace/boiler was drawing its combustion air from the refuse pit, odor would not escape from the building. However when one stands above the pit near the hoppers and near the primary air intake vent, the odors are most pronounced.

Harrisburg, Pennsylvania, U.S.A.

Battelle, under contract withh the U.S. EPA has been testing the hypothesis that the sulfur inherent in sewage sludge will (when mixed with chloride containing refuse in the pit) inhibit formation of corrosive chloride deposits on boiler tubes. Initial results are positive and promising.

Ingolstadt

Of the 30 plants visited in Europe by Battelle staff, 15 were viewed during two-hour walk-through tours. Ingolstadt, West Germany was viewed while 75 percent constructed. Figure W-12 shows a schematic of the plant. Because of the small print, the verbal description appearing at the bottom is repeated below:

> Activity One: Pretreated (filter-press, vacuum or centrifugally dried) sludge with a moisture content of 75-80 percent H_2O is charged into a hopper and transported by a chain conveyor to the storage tank (sludge silo) that is equipped with a mixing device. Controllable screw-conveyors extract the sludge from the storage tank and transport it to the twin mixing worm.
>
> Activity Two: This twinmixing worm is also fed with already dry sludge that is mixed with the wet sludge to a mixture of sludge with a mositure content of 35-40 percent H_2O. After this mixing the sludge in trickling form is inserted into the flue gas down duct. The flue gases are extracted from the refuse incineration combustion chamber with an approximate temperature of 850 degree C (1600 degree F) and fall downwards together with the sludge to a hammermill. Before the hot gases and the sludge reach the hammermill, the heat exchanger and evaporation and drying process starts. In the mill the sludge is disintegrated in very small particles (dust) and dried under the influence of heat.
>
> Activity Three: The gas-sludge mixture is transported through a vertical upwards duct (suspension dryer), where final drying takes place. In a cyclone the sludge is separated from the flue gases and falls via a rotary vlave and a duct into the dry sludge storage tank (intermediate bunker). The moist flue gases are further cleaned in a multicyclone ane reintroduced into the combustion chamber by aid of an exhaust vapor fan. The flue gas sstream is controlled by dampers and can be bypassed into the extracted flue gas stream to maintain a set temperature. The separated, dry sludge with a moisture content 5-15 percent H_2O in the intermediate storage tank can be extracted via rotary valves and be used as follows:
>
> - to be mixed with the wet sludge
> - to be introduced and burned in the combustion chamber in suspension above the grates
> - to be filled into bags for use as fertillizer, depending on contamination, especially heavy metals.
>
> A certain amount of dried sludge has to be stored in the intermediate tank for the purpose of mixing to the wet sludge at start-ups.
> Whenever necessary the installation is insulated against heat losses. An automatically operated measurement and control system allows supervision and control of the installation from the main control room.
>
> Activity Four: Sludge incineration. A fan generates the necessary air for pneumatic transprot of the dry sludge to the refuse incineration combustion chamber. The sludge burners are developed to

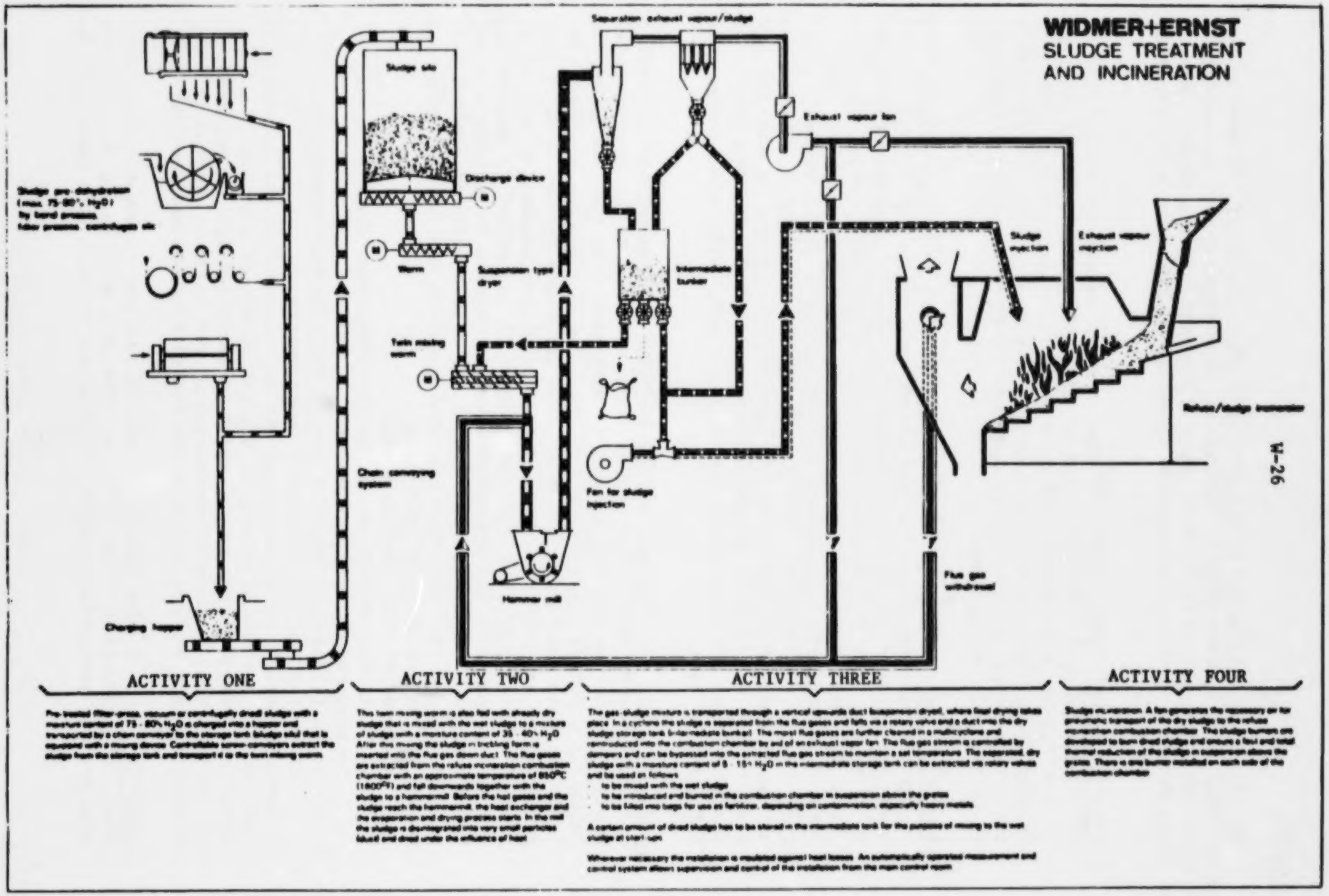

WIDMER+ERNST
SLUDGE TREATMENT
AND INCINERATION
Charging hopper
Discharge device
Hammer mill
ACTIVITY ONE
ACTIVITY TWO
ACTIVITY THREE
ACTIVITY FOUR

FIGURE W-12. CO-DISPOSAL OF REFUSE AND SEWAGE SLUDGE AT INGOLSTADT, WEST GERMANY burn dried sludge and ensure a fast and total thermal reduction of the sludge in suspension above the gates. There is one burner installed on each side of the combustion chamber.

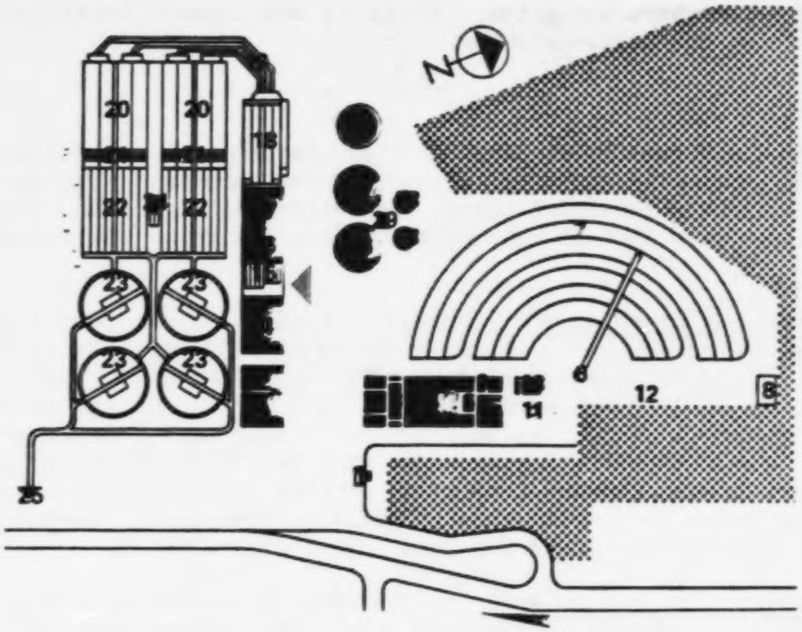
Biel

The Mura, Binne environmental part at Biel, Switzerland was another plant briefly visited. Figures W-13 and W-14 present the overhead plan and actual view of this wastewater treatment plant, the co-treatment plant and the compost area. These researchers made no attempt to collect design or operating data.

Aerobic Composting Danoklin Plus Bridge. Refuse is received and either goes to a Bema shredder or a Buhler hammermill. Some of the sized-reduced material along with sewage sludge is injected into a Dano rotary kiln. (See Figure W-15) where the residence time is 2 to 3 days. At the drum exit, the material is screened. Particles under 25 mm (1 inch) are transported to the outside composting area shown in Figure W-16. The rotating bridge turns the material over two times per week so that aerobic decomposition can continue. This continues for 4 to 5 month prior to sale to vineyards. Some of the material is further sieved and sold as pig feed. (See Figure W-17).

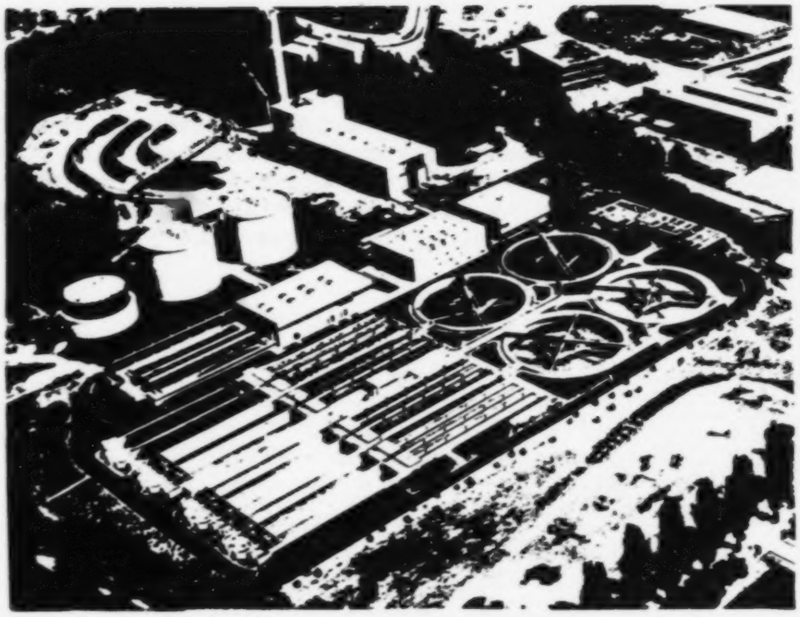
Anaerobic Composting (Bricolari Press). The other size-reduced refuse and sewage goes through (1) a trommel (60 mm mush size), (2) a high speed rotor to separate glass, (3) a second screening to collect particles under 6 mm (.25 inch), (4) a buffer storage. Sewage sludge is then dried slightly from 95 percent to 80 percent water in a centrifuge. Next, the refuse (less than 6 mm in size) is mixed with the sewage sludge (80 percent water) in a double screw mixer.

The Bricolari compactor press then produces the 600 x 200 x 200 mm (24 x 8 x 8 inch) bricks at a combined moisture content of 50 to 55 percent water. The bricks are stacked as shown in Figure W-18 for 4 to 5 weeks. The apparent advantage to the Bricolari process over the Dano/kiln/bridge aerating system in several fold. The Bricolari process, being aerobic requires less time thus permitting higher turnover and less land use. Once the Bricolari brick is formed and slacked, there is no activity uutil shipment. To repeat this compares with the aerobic turning of material by the crane 2 to 3 timer per week for 4 to 6 months.



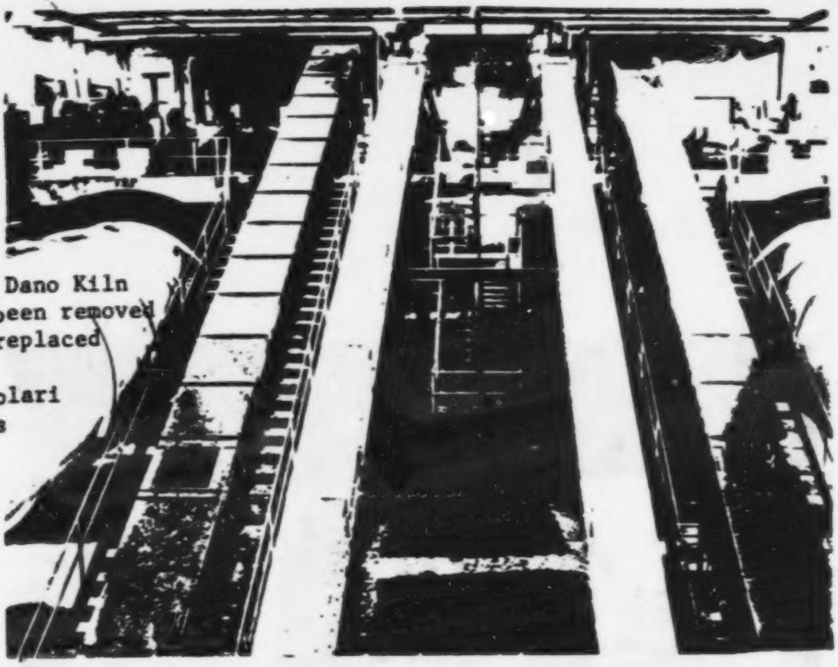
A	Administration
B	Workshops
C	Cloakroom, Showers, Restrooms, Cafeteria
1	Balance Bridge (30 t)
2	3 Refuse Silos
3	Composting Control Room
4	Biological Stabilizer Halls
5	Sifting Room
6	Compost Unloading Bridge
7	Layers Location
8	Quality Composting Hall
9	Silo for Sifting Residues and for Industrial Wastes
10	Furnace
11	Smoke Stack
12	Slags Location
13	Used Oils Settling

FIGURE W-13. OVERHEAD PLAN FOR THE ENVIRONMENTAL PARK AT BIEL, SWITZERLAND



14	Room for Compressors, heating equipment and emergency generator	
15	Screw Pump Station	
16	Control Room	
17	Mechanical Grate	
18	Oil-Sand Separator	
19	Flow Channels	
20	Primary Settling Basin	
21	Rainwater Discharge	
22	Aeration Tank	
23	Secondary Settling Basis	
24	Mud Recirculating Screw Pumps	
25	Discharge into the Nidau-Büren Canel	
26	Primary	Digestion Tank
27	Secondary	
28	Thickeness	
29	Stairway, Methane Gas Desulfuration	
30	Gasmeter	

FIGURE W-14. AERIAL PHOTO OF ENVIRONMENTAL PARK AT BIEL, SWITZERLAND



This Dano Kiln
has been removed
and replaced
by a
Bricolari
Press

FIGURE W-15. ORIGINAL DANO KILNS FOR COMPOST INITIATION
AT BIEL, SWITZERLAND (RETENTION TIME 2-3 DAYS)

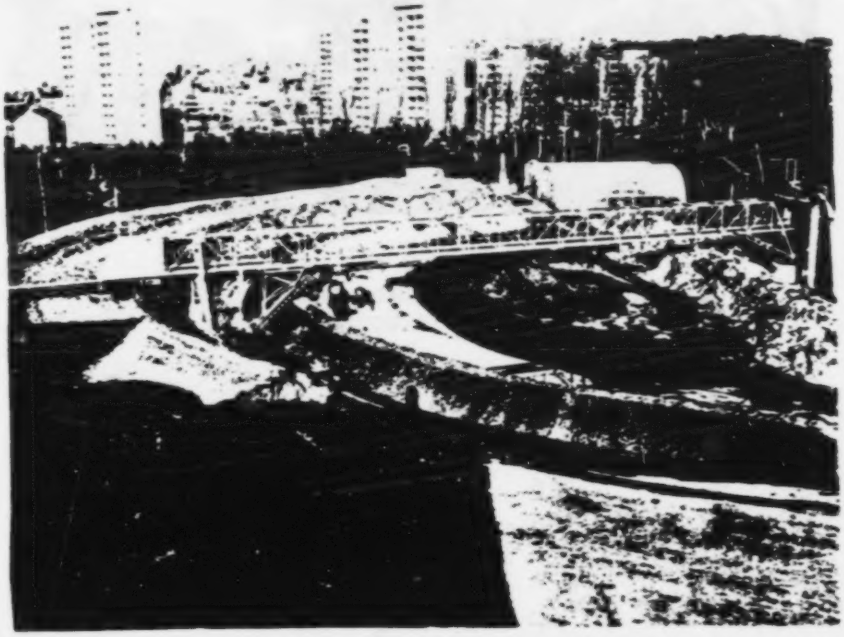


FIGURE W-16. AERATION TURNING BY PIVOT BRIDGE
FINAL COMPOSTER AT BIEL, SWITZERLAND
(RETENTION TIME 4-6 MONTHS).
(Notice residential neighborhood
in background).

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UFA
303
FIT
MÜRA
MULL

FIGURE W-17. PIG FEED MADE FROM DIGESTED SEWAGE SLUDGE AND REFUSE

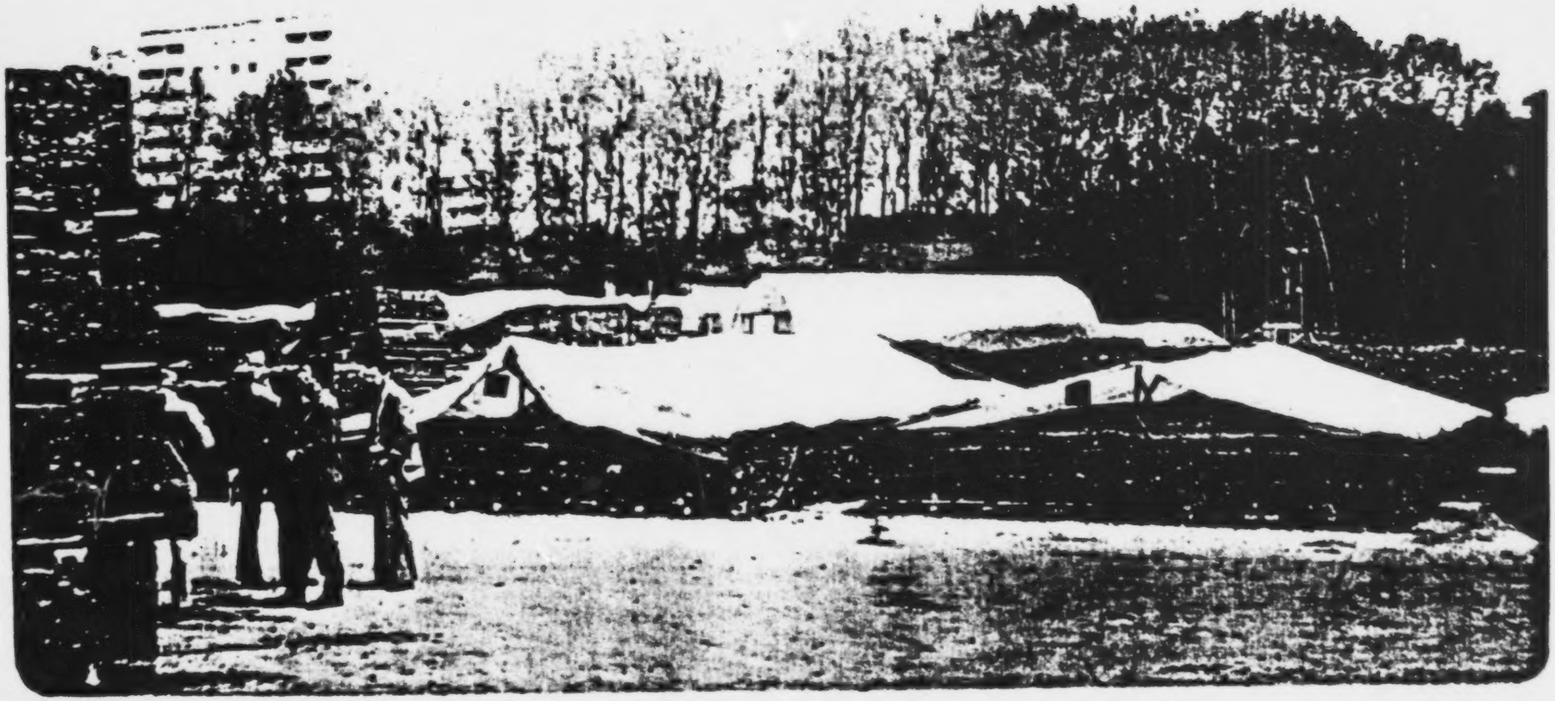

FIGURE W-18. BRICOLARI COMPOST STORAGE YARD (4-5 WEEKS)
WITH PIG FEED BUILDINGS IN BACKGROUND
AT BIEL, SWITZERLAND

AIR POLLUTION CONTROL

Development of Emission Controls

Particulates

The emergence of the refuse-fired steam generator in Europe in the 1960's was a direct result of the growing desire for pollution control-particularly control of flyash that made nuisances of many old incinerators. That is, the very dusty, hot gases from the incineration process had to be cooled before practical high efficiency flyash control could be applied; and the most logical means for cooling that gas is by means of a boiler to produce useful hot water or steam. In some cases, usually small plants, where energy recovery was not attractive, the gas cooling has been achieved not through heat recovery but by means of water sprays or air-cooled heat exchangers. However this energy wasteful practice has not become widespread.

Regardless of the method used for cooling of the dusty flue gas, the almost universal method for particulate removal from the partly cooled gases has been electrostatic precipitation, (ESP). Here again the considerable experience already developed in coal-burning practice was available to guide the application of ESP's to RFSG. One attempt was made to apply cloth filtration (baghouse) at Neuchatel but, although the system is still in operation, the results obtained were not outstanding.

Table X-1 shows the characteristics of the ESP's at the plants visited.

Precipitator Maintenance

Reliability of ESP's has been excellent except where the inlet gases have been too hot: above about 260 C (500 F). This has caused very rapid corrosion and deterioration of the precipitator. In most cases this overheating has been caused by an unanticipated increase in the heat value of the municipal refuse or wearing of the grate systems. Then if the boiler heating surfaces were not amply designed to cope with the resulting excessive heat release in the boiler-furnace, the gases pass on to the precipitator at high enough temperature to cause serious corrosion. In some cases this overheating may not occur until toward the end of a long period of operation when the heating surfaces are heavily coated by ash. Many plants then shut down for thorough boiler cleaning, usually after 3000 to 4000 hours.

Gases

Some attention is now being given to controlling gaseous emissions - HCl, HF and SO_2. However these gases are not emitted in high concentrations, and their ambient levels in the vicinity of even the largest plants is probably so low that no attempts have been made to measure nor to estimate them continuously in the surrounding air. Instead their control is considered just because they are perceived to be bad. At

TABLE X-1. CHARACTERISTICS OF ELECTROSTATIC PRECIPITATORS

	Year	Nominal Plant Capacity	Unit Capacity	Number of ESP	Gas Volume Per Unit		Design	Velocity	Number of Fields	Projected Collection Surface		Residence Time	Voltage	Sparking Voltage	Maximum Current	Total Power	Measured Dust Load				Loading Corrected to CO_2	Test Effic.
																	In	In	Out	Out		
		tonnes per day	tonnes per hr		Nm^3/h x10^{-3}	acfm x10^{-3}	m/s	f/s		m^2	ft^2	sec	KV	KV	ma	KVA	g/Nm^3	gr/acf	mg/Nm^3	gr/scf	%	%
Werdenberg	1974	120	5.0	1	83.0	48.8	0.67	2.2	1	1,142	12,288	5.9	-	-	600	45	-	-	88	-	7	-
Baden-Brugg	1970	200	3.3	2	64.0	37.7	0.70	2.3	1	952	10,247	5.9	55	-	506	55	-	-	110	-	7	97.8
Dusseldorf	1965	1,260	10.0	3	39.0	22.9	1.1	3.7	2	2,020	20,800	5.2	31	-	-	-	13.1	5.69	42	0.0184	(7)	99.68
	1972		12.5	1			0.8	2.7	2	3,600	38,730	7.2	78	-	900	95.5	-	-	-	-	-	-
Wuppertal	1976	1,440	15.0	4	100.0	58.9	1.0	3.3	2	2,810	30,230	7.0	45	64	600	92	-	-	-	-	-	-
Krefeld	1976	576	12.0	2	86.0	50.6	1.0	3.3	2	2,810	30,230	7.0	45	64	600	92	4.5	1.97	100	0.0438	7	-
Paris:Issy	1965	1,635	17.0	4	100.0	58.9	0.9	3.0	2	-	-	-	76	-	420	30	-	-	36-59	0.015-0.026	7	-
Hamburg:S-M	1972	1,180	18.8	2	90.6	-	1.15	3.8	2	-	-	-	-	-	-	-	-	-	50-80	0.02-0.035	7	-
Zurich:Hagenholz	1973	380[(1)]	21.0	1	95.6	-	0.81	2.7	2	3,560	38,306	-	78	-	2,430	-	-	-	42	0.018	7	98.3
The Hague	1965	1,440	15.0	4	90.0	52.9	2.0	6.5	2	-	-	-	40	-	500	-	-	-	55[(3)]	0.024	7	-
Deauville[(2)]	1976	67	2.8	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	600[(2)]	0.26	7	-
Gothenberg	1970	1,080	15.0	3	100.0	58.9	1.15	3.8	2	-	-	4.8	-	-	-	-	-	-	150[(4)]	0.065	10	-
Uppsala	1970	120[(1)]	5.0	1	29.3	17.3	0.71	2.3	-	-	-	-	32	-	-	-	0.69	0.30	15	0.007	-	98.1
Horsens	1974	120	5.0	1	36.0	21.2	0.48	1.6	2	-	-	-	50	-	800	-	-	-	178	0.078	10	-
Copenhagen:Amager	1970	864	12.0	3	107.0	63.0	0.86	2.8	2	-	-	-	-	-	-	-	7.5	3.26	60-90	0.026-0.039	-	-
Copenhagen:West	1970	1,152	12.0	3	107.0	63.0	0.86	2.8	2	-	-	-	-	-	-	-	7.5	3.26	90	0.039	-	-

(1) Only the newest unit in this plant is considered here.

(2) Dieppe has centrifugal dust collection; Deauville has ESP, but for this small plant French regulations permit emission up to 600 mg/Nm^3 (0.26 gr/scf).

(3) Unit No. 4 tested in 1974 had an emission of only 19 mg/Nm^3 at 7% CO_2 corresponding to an efficiency of 99.6%. With only one field its efficiency was 85%.

(4) The original installation had to be augmented by additional collection surface to attain the guaranteed emission of 150 mg/Nm^3 (0.065 gr/scf).

present only in West Germany are new or modified plants now required to control gaseous emissions. The emission permitted levels (at OC, 32 F, corrected to 7 percent CO_2) are:

HCl: 100 mg/Nm^3 (62 ppm) 0.083 lb/1000 lb gas
HF: 5 mg/Nm^3 (11 ppm) 0.008 lb/1000 lb gas
SO_2 500 mg/Nm^3 (175 ppm) 0.46 lb/1000 lb gas .
(only in areas with high ambient SO_x levels)

Accordingly only in Germany are scrubbers being tried. None was working satisfactorily at the new plants visited which had just installed new scrubbers. However, except for the very major maintenance problem always caused by the corrosiveness of acidic scrubber water, HCl should not be difficult to control because it is highly soluble in water. HF should also be absorbed in a scrubber but the scant data available on HF emissions indicates that the German limit of 11 ppm at 7 percent CO_2 is readily met without scrubbers. Similarly, the sulfur content of refuse is so low that the probable capture of 25 to 59 percent of the sulfur by the alkalis in the ash means that SO_2 control will often be unnecessary to meet the 175 ppm emission limit in Germany.

One vexing aspect of scrubbers is that the saturated gas leaving the scrubber often creates a highly visible white steam plume. It may actually be a very clean plume but its appearance calls attention to possible emissions. Also if conditions are such as to produce large water droplets in the plume the resulting "rain" will be acidic because no scrubber removes 100 percent of the acid gas. The solution to a white plume and its acid rain is to reheat the plume to about 80 C (176 F) by means of steam-heated heat exchangers. However, reheaters consume energy and are subject to plugging and corrosion. One practical solution to this problem will be used at Wuppertal. The plan is to scrub a major part but not all of the gas to a level surpassing the allowable limit, meanwhile by passing the uncleaned portion of the hot gas to a mixing and reheat section. The resulting reheated mixture can then be discharged without visible plume or acid rain while still being within the allowable emission limit.

Measured Gaseous Emissions

Table X-2 shows the results of emissions measurements at selected plants. The very large differences in HCl emissions among the plants is expalinable only by the great diversity of materials in MSW. Probably variations in the amount of polyvinyl chloride burned is the major cause of the large differences.

Gaseous Emission Limits

Table X-3 shows the emission limits applicable to refuse burning in the countries visited.

So far only in Germany and Sweden is there any limit on gaseous emissions, and even in Sweden the value of 40 mg/Nm^3 (approx. 20 ppm) of total acid gases is not a limit but a signal: if a plant exceeds that emission level it must undertake a study of feasible means to control emission. Presumably then actual control requirements will depend on the

TABLE X-2. MEASURED GASEOUS EMISSION RATES AT EUROPEAN RFSG
(Numbers in parenthesis indicate CO$_2$ level to which the concentration is adjusted)

PLANT	CO$_2$ %	HCl mg/Nm^3	HF mg/Nm^3	SO$_2$+SO$_3$ mg/Nm^3	NO$_x$ mg/Nm^3	OTHER mg/Nm^3
Dusseldorf	-	1,000(11)	9(11)	505(11)	9(11)	-
Paris:Issy	6.1-7.1	1,074-1,744(7)	-	126-139(7)	97-163(7)	-
Zurich:Hagenholz	7.7-8.4	531-840	11	219-220	-	-
Uppsala	6.4	22-114(10)	-	90-330(10)	-	-
Copenhagen:Amager	-	700-900(7)	-	200-300(7)	-	-
Anonymous French Plant(1)	8.8	430(7)	-	82(7)	40(7)	2.6(2)

(1) At the anonymous French plant, the sum of organic acids, aldehydes, ketones, alcohols, phenols, polyphenols, aliphatics, and cyclic and polycyclic compounds was 2.6 mg/Nm^3.

(2) Other organic compounds of N, S, and Cl totaled 0.2 mg/Nm^3.

Conversion to get ppm: HCl, multiply mg/Nm^3 by 0.62
HF " " " 1.12
(OC, 32F) SO$_2$ " " " 0.35
NO$_x$ " " " 0.47 (as NO$_2$)

TABLE X-3. EMISSION LIMITS, mg/Nm^3
(Parentheses indicate CO_2 level to which the concentration is adjusted)

COUNTRY		PARTICULATES	HCl	HF	SO_2
		mg/Nm^3	mg/Nm^3	mg/Nm^3	mg/Nm^3
W. Germany		100(7)	100(7)	5(7)	500(7)
Switzerland		100(7)	500(7)	-	300(7)
France	1 tonne/hr	1,000(7)	-	-	-
	1-4 tonne/hr	600			
	4-7 tonne/hr	250			
	7-(15)tonne/hr	150			
	(1)over(15)tonne/hr	80			
Holland		100(7)	-	-	-
Sweden		180(10)	40(10)(2)	-(2)	-(2)
Denmark	small plants	180(10)	-	-	-
	large plants	150 (11)	1,500	-	1,500(3)
USA		180	-	-	-

(1) Estimated from incomplete data.

(2) Total acid equivalent - Exceeding this total, 40 mg/Nm^3 for all acid gases, feasible control system.

(3) SO_2 plus SO_3.

The conversions to volume units are:

HCl	multiply	mg/Nm^3	by	0.62	to get ppm
HF	"	"	"	1.12	to get ppm
SO^2	"	"	"	0.35	to get ppm

To convert particulates: mg/Nm^3 to grains/scf, multiply by 43 x 10^{-5}

cost of feasible control and whether the need for improvement in local atmospheric quality levels warrant that expenditure.

Trends in Emissions Control

As can be seen from Table X-3 and the prior discussion, particulate control in these plants is excellent and high standards are regularly achieved. There is no strong trend in Europe to further control particles nor to control gaseous emissions. Many agencies appear to be awaiting the demonstrated effectiveness and reliability of the acid gas scrubbers now going through normal problems of startup in Germany at Wuppertal, Krefield and Kiel which latter plant was visited briefly. If these eventually prove out to be as effective, maintainable and relatively as economical as ESP's there will probably be a trend to apply them more widely, especially in densely populated areas where ambient pollution levels are high. On the other hand, there are no data available to demonstrate the specific needs for elimination of HCl and HF from the ambient air. Hence, if their removal turns out to be as formidable a task as SO_2 control has been for coal-fired plants, the control of HCl and HF emission may become limited to those situations where a specific measurable need can be shown.

Specific Comments about Air Pollution Control at Plants Visited

Werdenberg-Liechtenstein

During our 3-day visit to this plant, there was no visible plume most of the time and even when visible, it was only barely so againt a very clean sky. Pollution control at this small plant is by a single-field electrostatic precipitator by Elex. Without the hopper it is 9.3 m high, 5.7 m wide, and 5.9 m deep. It has a flow rate of 83,000 m^3/hr at (48,800 cfm) at 274 C (525 F). Average velocity is 0.67 m/sec (2.2 ft/sec). The gas composition and dewpoint at the precipitator during the compliance test was:

- CO_2 - 5.4 percent
- H_2O - 30.5 percent
- Dewpoint - 51 C (124 F).

Particulates are now limited to 100 mg/Nm^3 (0.0438 grains/ft^3) corrected to 7 percent CO_2. When tested, it achieved 88 mg/Nm^3 (0.038 grains/ft^3). Bypassing of precipitators has not been permitted since 1972.

The precipitator and its duct configuration were tested beforehand by Elex in a small water model to assure a uniform flow pattern. To distribute the gas flow ahead of the charging section, there are perforated plates in series containing 5 cm holes. The spacing of the collector plates is about 300 mm (11.8 in) providing 17 parallel flow passages. Residence time is 5.9 sec. Total plate area is 1,142 m^2 (12,288 ft^2) with a projected area of 952 m^2 (10,243 ft^3). The plates are cleaned imtermittently by a bottom rapper. The charging electrodes are cleaned by a rapper at the top.

Power consumption is 29 kw at 380 volts. Output capacity is 45 KVA at 78,000 volts and 600 ma.

The fly ash hoppers are approximately 50 degree inverted pyramids electrically heated and covered with 10 cm (4 in) of insulation. The collected ash is removed continuously by screw conveyors with discharge into the main residue quench tank.

The precipitator was guaranteed to achieve 97.5 percent efficiency and to emit no more than 100 mg/Nm^3, wet, at 7 percent CO_2.

So far, the precipitator has needed no repairs. It is cleaned once per year when the boiler is cleaned. For personnel protection, the access doors cannot be opened before an 8-multiple key sequence is processed.

To achieve even lower particulate emissions from future plants, the manufacturer is considering the use of two-field precipitators.

Baden-Brugg

There was no visible plume at any time during our 3-day visit to the Baden-Brugg plant. Pollution control is by 2 single-field Elex electrostatic precipitators followed by 2-stage multicyclones. Without the hopper the precipitators are 7 m high, 4.45 m wide, and 7 m deep. They have a flow rate of 64,000 Nm^3/hr. (37,664 scfm). Average velocity is 0.7 m/sec (2.3 ft/sec). The gas at the precipitator contains 6-7 percent carbon dioxide. Particulates are now limited to 100 mg/Nm^3. When this plant was designed, the allowable limit was 150 mg/Nm^3. When tested by the manufacturer, it achieved 110 mg/Nm^3. With the multi-cyclone alone the emission was 400 mg/Nm^3.

The precipitators and their duct configuration were tested beforehand by Elex in a small water model to assure a uniform flow pattern. Residence time is 5.9 sec. Total plate area is 612 m^2 (6587 ft^2) with a projected area of 952 m^2(10,247 ft^3). The plates are cleaned intermittently by a bottom rapper. The charging electrodes are cleaned by a rapper at the top. Output capacity is 55 KVA at 55,000 volts and 506 ma.

The fly ash hoppers are approximately 50 degree inverted pyramids electrically heated and covered with 10 cm (4 in) of insulation. The collected ash is removed continuously by star feeders with discharge directly downward into the main residue quench tank.

The precipitator was guaranteed to achieve 97 percent efficiency. Assuming an inlet loading of 5 grams/Nm^3 the measured efficiency was 97.8 percent.

So far, the precipitator has needed no repairs. It is cleaned once per year when the boiler is cleaned. For personnel protection, the access doors cannot be opened before an 8-multiple key sequence is processed.

To achieve even lower particulate emissions from future plants, the manufacturer is considering the use of two-field precipitators.

The precipitators have suffered no serious corrosion during the normal weekend shutdowns. Initially cracks in the porcelain insulators caused arcing but this was cleared up by replacing them with other ceramic insulators. In 29,000 hours of operation over 7 years there have been no electrodes not plates replaced.

Duesseldorf

The four original boilers at Duesseldorf which started in 1965 were equipped with two Lurgi Electrostatic Precipitators having a design efficiency of 99+ percent. In each precipitator, the gas flow is divided into 28 passages, each 0.226 m (8.5 in) wide. The height of the passage is 6.27 m (20.6 ft) and its flow length is 5.75 m (18.9 ft). Total projected collection area in each precipitator is 2020 m^2 (20,800 ft^2). The inlet flow area is 37.5 m^2 (406 ft^2) and the design velocity is 1.1 m/s (3.7 ft/s). Design flow rate was 39,000 Nm^3/hr (22,952 scfm).

Table X-4 by Konopka* gives the results of two precipitator tests at this plant in 1967 by the government testing organization, Technische Ubervachungs Verein Rheinland, e.v. (TUV). The report indicated that in one test, the combustible content of the collected dust was 6.6 percent and its resistivity at 220 C (432 F) was 6 x 10^7 ohm-cm. Similar values were recorded by TUV at Munich and Stuttgart.

Boilers No. 3 and 4 are served by an identical precipitator to that serving Nos. 1 and 2. Boiler No. 5 is served by a third precipitator. All three precipitators are connected by a manifold to a single chimney. By means of mulit-vane butterfly dampers, the flow from any two boilers can be fed to either three precipitators. The damper blades are 574 mm (22 in) wide and are shaped to present a "knife edge" to upstream and downstream flow when open. This shape helps to minimize deposition of ash on the blades. The upstream edge of each blade is made of manganese steel. To further discourage deposition and erosion, each blade is shielded upstream by a manganese steel I-bar positioned 20 mm (0.79 in) upstream. The damper assembly was made by Warmekraft-Gesellschaft-Stober Morlock of Recklinghausen, Germany.

The installation of precipitator No. 3 for Boiler No. 5 by Rothemulle in 1972 was preceded by a flow model study although the approaching flow pattern produced by the flue gas manifold was not modeled. It has two fields and 30 rows of collector plates spaced 300 mm (11.8 in) apart. The plates are 10 m (32.8 ft) high and each field is 3 m (9.8 ft) long. Effective projected collector surface is 3,600 m^2 (38,730 ft^2). Perforated distributor plates produced an excellent velocity flow distribution entering the first field at an average velocity of 0.834 m/s (2.74 f/s). Residence time is 7.2 seconds.

A power supply of 95.5 KVA is available to each field at 55 KV. No-flow voltage is 78 KV. Normal current is 600 ma, maximum 900 ma. Power consumption per field is 33 Kw.

Rapping is by means of gravity hammers operated automatically in a prescribed sequence. Unlike many outdoor precipitators, these hoppers are not heated. They are covered with 100 mm (3.9 in) of insulation. There is no problem of condensation causing sticking of the ash in the hoppers because there is no storage of fly ash there.

Originally, the ash removal system was pneumatic but this was abandoned after 2 years and was replaced by screws. Some modification of the fitting of the screws to the hoppers was needed to facilitate ash removal.

One 24-hour test by TUV showed the particulate emission rate to range from 30 to 100 mg/Nm^3 corrected to 11 percent CO_2 (0.0352 to 0.044 grains/ft^3).

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*Konopka, A.P., "Systems Evaluation of Refuse as a Low Sulfur Fuel, Part 3 - Air Pollution Aspects", ASME Preprint 71-WA/Inc-1, 1971, ASME, New York, NY, 10017.

TABLE X-4. RESULTS OF TWO PERFORMANCE TESTS BY TUV ON A PRECIPITATOR AT THE DUESSELDORF REFUSE PLANT

Test Number	1	2
Firing Mode	Refuse	Refuse
Rated Gas Volumes m^3/S °C	44.0@260 C	44.0@260 C
ft^3/S °F (V Design)	1,550.0@500 F	1,550.0@500 F
Actual Gas Volume m^3/S °C (Measured at ESP Outlet)	43.0@235 C	43.5@242 C
ft^3/S °F (V Actual)	1,520.0@455 F	1,535.0@460 F
1,000 ACFM °F	91.0@455 F	92.0@405 F
Percent of Rating (Percent)	97.7	98.9
Actual (Test) ESP Inlet Dust Conc. (g/Nm^3)	11.0	13.1
(gr/SCF)	4.31	5.69
Actual (Test) ESP Outlet Dust Conc. (g/Nm^3)	0.036	0.042
(gr/SCF)	0.0158	0.0184
Guaranteed Collection Efficiency (Corrected for Actual Test Conditions per Manufacturer's Corrosion Factors (Percent)	98.35	98.95
Actual (Test Collection Efficiency) (Percent)	99.67	99.68
ESP Design Gas Velocity at Rated Volume (m/sec)	1.16	1.16
(ft/sec)	3.82	3.82
ESP Actual (Test) Gas Velocity (v) (m/sec)	1.14	1.15
(ft/sec)	3.74	3.77
Design Migration Velocity (ft/sec)	0.408	0.319
Actual Migration Velocity (ft/sec)	0.399	0.406
ESP Electrical Energization Data		
Secondary Kilovolts Inlet (KV) (Inlet/Outlet)	31.5/29	31/29
Secondary Mill-amps (MA) (Inlet/Outlet)	265/267	313/310
Input Power (Kilowatts) (Inlet/Outlet)	8.3/7.7	9.7/9.0
Power Density-Watts per 1,000 ACFM (Inlet/Outlet)	91.7/85	105/97.7
Power Density-Watts per ft^2 (Inlet/Outlet)	0.401/0.372	0.466/0.432
Field Strength-Kilovolts per Inch (Inlet/Outlet)	0.74/0.68	0.73/0.68

NOTE: N = corrected to 0°C and 760 mm Hg; 0.0736 mm Hg. water vapor pressure.

The applied voltage on the precipitators must be continuously recorded as required by the county licensing board. The record must be stored for 5 years.

The availability for service of the individual precipitators is shown by the record for a 2-year period:

	Availability, Percent	
	1975	1976
Precipitator No. 1	99.3	99.2
Precipitator No. 2	99.6	100.0
Precipitator No. 3	100.0	92.7

Figure X-1 is an example of two of the operation and maintenance computer cards which are used at the plant to maintain systematic records on the precipitators and other components.

Wuppertal

Scrubber. The pollution control equipment at Wuppertal is unique in that the four conventional electrostatic precipitators are followed by two scrubbers to remove most of the HCl and HF emitted. At the time of the plant visit, May 1977, the scrubber system was still under construction, hence, no data are available on scrubber performance. The performance criteria is that emission of HCl shall not exceed 100 mg/Nm^3 corrected to 7 percent CO_2. The ducting is arranged so that when, as normal, three units are burning, the gases from only two will pass through the scrubbers. The unscrubbed hot gases will then be mixed with the cool, scrubbed gases, about 60 C (140 F), for purposes of reheat to about 200 C (390 F) to augment exhaust plume buoyancy and invisibility.

Precipitator. The four electrostatic precipitators were manufactured by Buttner-Schilde-Haas under license from Svenska Flaktfabriken. They are 7.95 m high, 7.15 m wide, and 10.2 m deep (26 x 23 x 33 ft). Table X-5 shows the precipitator design characteristics. struction was not preceded by a flow model investigation. No performance data were available at the time of the visit, May 1977.

At first there was some problem with ash buildup in the fly ash hoppers but an increased slope of the hopper sides eliminated that problem.

Initially, there was some problem from vibration of the induced draft fans caused by dust deposits on the blades. Improved control of burning appears to have eliminated that problem.

At the time of the visit the scrubbers were not yet completed and the precipitators had not been tested. The appearance of the stack plume and plant was extremely clean and attractive.

A striking and very unique indication of the need to keep this plant clean is that a public swimming pool is within clear sight of the plant in the narrow valley below. Figure X-2 showing the pool, was photographed from the plant conference room window. The distance from the plant property to the pool is about 120 m (400 ft).

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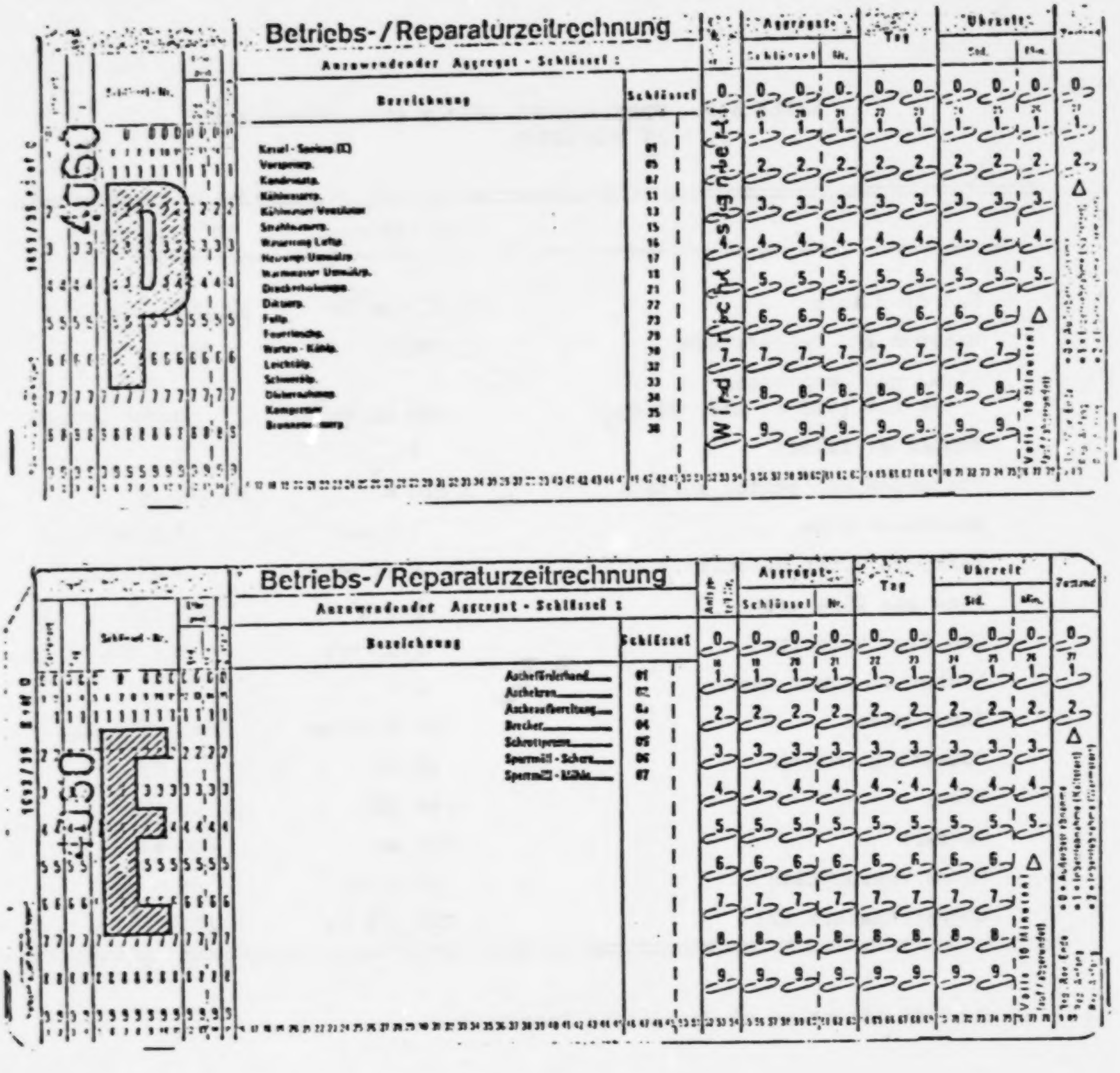


Betriebs-/Reparaturzeitrechnung

Anzuwendender Aggregat - Schlüssel :

Bezeichnung	Schlüssel

Betriebs-/Reparaturzeitrechnung

Anzuwendender Aggregat - Schlüssel :

Bezeichnung	Schlüssel
Aschefürderband	01
Aschekran	02
Ascheaufbereitung	03
Brecher	04
Schrottpresse	05
Sperrmüll - Schere	06
Sperrmüll - Mühle	07

FIGURE X-1. SAMPLE DATA CARDS AS USED IN PLANT DATA SYSTEM AT DUESSELDORF.

TABLE X-5. PRECIPITATOR DESIGN CHARACTERISTICS AT WUPPERTAL

	SI Units	ENG. Units
Gas flow rate	100,000 Nm^3/h	58,860 scfm
Maximum gas temperature	290 C	554 F
Clean gas conditions (at 220 [428 F] and 8% CO_2)	100 mg/Nm^3	0.044 gr/scf
Number of fields	2	2
Projected collecting surface	2,810 m^2	30,230 ft^2
Residence time	7.0 sec	7.0 sec
Particle drift velocity	8.24 cm/s	0.23 f/s
Free gas flow area	48.8 m^2	525 ft^2
Gas flow velocity	1.03 m/s	3.4 f/s
Number of power packs	2	2
Input power	380 V/50 hz	380 V/50 hz
Operating voltage	45 KV	45 KV
Power	46 KVA	46 KVA
Current	600 mA	600 mA
Power consumption	27.6 kw	27.6 kw
Hopper heaters (2)	220 V/8 kw	220 V/8 kw

Source: Courtesy of Vereinigte Kesselwerke.

FIGURE X-2. DOWNWARD VIEW FROM THE WUPPERTAL PLANT SHOWING THE NEARBY COUNTRY CLUB AND SWIMMING POOL (Battelle Photo).

Krefeld Co-disposal Plant

At the refuse-sludge co-disposal plant at Krefeld, the exhaust gases are cleaned by two electrostatic precipitators and by two scrubbers. Table X-6 gives the design characteristics of the precipitators. No test data are yet available on precipitator performance. The precipitator was built by Buttner-Schilde-Haas of Krefeld, a member of the Babcock group, under license from Svenska Flaktfabriken. While visiting this plant, May 20 and 23, 1977, the stack plume from single boiler operation was usually invisible. At one period, during startup with the heavy oil burner, some smoke was observed, apparently because the system was cold and the outer portions of the oil flame were quenched before combustion was complete.

Scrubbers at Krefeld. In accordance with the new Federal Regulation of 1974, referred to earlier as T. A. Luft, a scrubber system has been added to the Krefeld plant following the precipitator and also following the induced draft fan. The scrubbers installed by Lugar are designed to achieve the following emissions:

HCl: 100 mg/Nm^3
SO_2: 100 mg/Nm^3
HF : 5 mg/Nm^3
NO_x: 265 mg/Nm^3 (Not subject to regulation)
All corrected to 7 percent CO_2.

Figure X-3 shows the water systems for the entire plant including the scrubber. The sketch of the scrubbers implies that the scrubbers are simple vertical spray-type units with some provision for demisting. A separate fan and steam-heated air heater is used for mixing hot air with the cool, saturated gases leaving each scrubber.

No test data are yet available on the flue gas cleaning system. Assuming that the scrubber system can be brought to a high level of reliable operation, this plant will then become one of the most advanced waste-to-energy plants in the world .

Paris: Issy

The Issy-les-Moulineaux plant in Paris is relatively old (1965) but has excellent emission control. The four furnaces, each with a Lurgi electrostatic precipitator (ESP) feed into two chimneys.

Furnace Exit Conditions. Each boiler supplies 130,000-150,000 Nm^3/hr of 300 C (572 F) temperature combustion gases to the precipitators.

A typical boiler exit gas composition adjusted to 7 percent CO_2 is as follows:

• Particulates	2000 to 5000 mg/Nm^3
• CO_2	7 percent
• O_2	11 percent
• N_2	69 percent
• H_2O	13 percent
• SO_2	100 to 400 mg/Nm^3(35 to 140 ppm)
• NO_x	100 to 200 mg/Nm^3 (49 to 98 ppm)

TABLE X-6. CHARACTERISTICS OF THE TWO KREFELD PRECIPITATORS

Gas quantity	86,000 Nm^3/h
Gas temperature	300° C
Raw gas dust load at 10% CO_2	4.5 g/Nm^3
Cleaned gas dust load at 7% CO_2	100 mg/Nm^3
Number of electrical fields	2
Number of rapped fields	2
Active length	7.2 m
Active width	6.5 m
Active height	7.5 m
Gas passages	26
Active volume	351 m^3
Collector plate projected area	2,810 m^2
Collector plate effective area	3,800 m^2
Gas velocity	1.025 m/s
Cross sectional area	48.75 m^2
Residence time	7.02 s
Drift velocity	3.29 m/s
Number of power supplies	2
Electrical characteristics	45 kV eff.
Sparking voltage	64 kV_s
Secondary current	600 mA_m
Sparking current	1,020 mA eff.
Power input per field	46 kVa
Power consumption	27.6 kW
Power to rappers	4 x 0.055 kW
Insulation heaters	8 x 2.0 kW
Current density	0.426 mA/m^2
Sparking current density	3.42 mA/m^3

Source: Courtesy Vereinigte Kesselwerke.

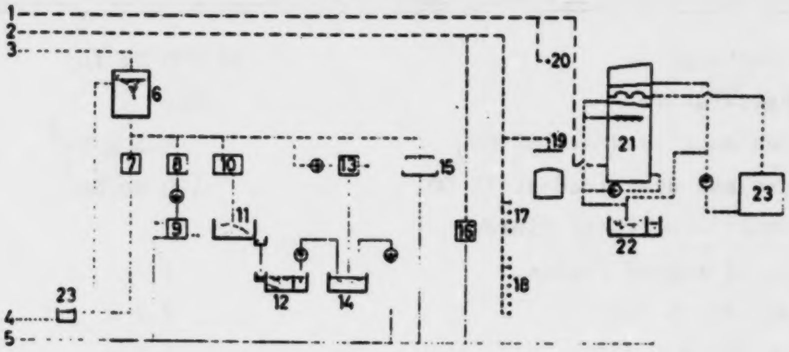


FIGURE X-3. SUPPLY AND WASTEWATER SYSTEMS AT KREFELD.

1. Clear water from wastewater treatment plant
2. City water
3. Well water
4. Percolation well
5. Wastewater canal
6. Well water reservoir
7. Cold water discharge
8. Flocculating tank
9. Sludge centrifuge
10. Quench tank
11. Ash bunker
12. Settling tank
13. Boiler feedwater treatment
14. Neutralizing tank
15. Washroom
16. Sanitary wastes
17. Exterior hydrants
18. Tipping floor hydrants
19. Fire control cannon-bunker
20. Oil tank
21. Flue gas scrubber
22. Neutralization tank
23. Lime mixing tank

- HCl 1100 to 1600 mg/Nm^3 (685 to 1000 ppm)
- HF traces

The particle size distribution less than 10 uM is 7.5 percent to 10.0 percent.

Precipitator Characteristics. Disregarding the hopper, each precipitator is 15.5 m (51 feet) high 9.2 m (30 feet) wide and 10.2 m (33 feet) deep. A dividin guillotine damper wall is located inside each precipitator. This permits half a precipitator to operate if the other half is under repair. The design was not preceeded by a flow-model study.

The average flow velocity in the ESP is 0.925 m (3 feet) per second. Two perforated plates at the ESP entrance uniformly distribute the gas flow. The units have two (2) fields in series. Each unit has 4,320 collection plates that are approximately 40 cm (15.7 in.) wide and curved at each edge. These collector plates are spaced 20 cm (7.9 in.) from the wires. The impact of falling hammers cleans the plates.

The output voltage is 76,000 volts and the output current is 0.42 amperes. The capacity is 30 Kva.

The pyramidal fly ash hoppers have no method for heating. Flyash is removed pneumatically. Ivry also has pneumatic removal but later Martin installations have used screws to remove flyash. Efficiency was guaranteed at 98 percent.

A notable philosophy of TIRU management is that full air pollution stack tests are conducted once per month. This is discussed later under stack sampling methods. Table X-7 shows the results of 4 tests in February 1977. The particulate emissions are well within the allowable 80 mg/Nm^3 corrected to 7 percent CO_2 which is the limit for this large refuse-burning plant.

Hamburg: Stellinger-Moor

Because of high-firing rates and high heat values the gas temperature entering the 2 precipitators at the Stellinger-Moor plant have suffered.

Stage 1. (Original Construction). The two-field ESP manufactured by Rothemuhle was designed to process 90,560 Nm^3/hr (53,250 scfm) when the furnace is operated at 130 percent of nominal capacity.

The flue gas entering temperature had been around 350 C (662 F). This is well above recommended temperature levels and has been the source of high temperature corrosion and mediocre performance of the ESP. The exit temperatures ranged from 250 to 300 C (482 to 572 F).

The maximum flow velocity is 1.16 m/sec (3.8 feet/sec). The insulation is 8 cm (3.1 in) thick.

Mechanical rappers remove the flyash which falls into the pyramidal hoppers. In wintertime, the hoppers are heated electrically. Flyash is removed by a service conveyor leading to the residue conveyor.

The guaranteed particulate efficiency was 98.9 percent. The original construction had a single duct leading from the bottom of the economizer section to the electrostatic precipitator (ESP) on the building roof. With all new equipment and with much supervision, the plant had

TABLE X-7. PARIS-ISSY AIR POLLUTION TEST RESULTS

		Furnace			
	UNITS	No. 1	No. 2	No. 3	No. 4
Date (1977)		2/28	2/25	2/23	2/22
Rate of Incineration	(refuse tonnes/ hour)	20.11	19.16	15.73	18.43
Rate of Steam Production	(Steam tonnes/ hour)	30.82	32.46	28.97	31.11
Temperature at Furnace Roof	(° C)	880	928	956	896
Temperature at Boiler Exit	(° C)	334	308	388	283
Volume leaving ESP	(Nm^3/hour)	100,190	95,250	97,910	108,910
Humidity leaving ESP	(%)	12.2	13.1	16.8	11.9
Emission Leaving ESP	(%)				
CO_2		6.1	6.5	7.1	6.2
O_2		11.0	10.8	9.4	11.1
Particulates (@7% CO_2)	(mg/Nm^3)	42	36	59	47
SO_2 and SO_3 (@7% CO_2)	(mg/Nm^3)	126	130	132	139
NO and NO_2 (@7% CO_2)	(mg/Nm^3)	97	141	138	163
HCl (@7% CO_2)	(mg/Nm^3)	1,335	1,509	1,744	1,074

Source: TIRU Division Controle Technique
Section Laboratoire et Essais

passed the air pollution compliance test with readings between 112 and 145 mg/Nm^3 which were below the legal limit of 150 mg/Nm^3 (9.065 gr/scf) adjusted to 7 percent CO_2.

As the years have passed, with the equipment becoming older and somewhat corroded, plant operations may be more casual and on some occassions the refuse feeding may be jerky. For whatever combinatin of reasons, the later air pollution tests showed a 200 mg/Nm^3 (0.087 gr/scf) result. This was unacceptable and something had to be done.

Stage 2. (Flue Gas Water Spray Cooler). In 1975, a flue gas water spray cooler was added and began spraying 1100 liters per hour (4.8 gal/min) or 1.1 tonne/hour (1.2 ton/hour) of water. The ensuing tests showed that particulate emissions had decreased to 50 to 80 mg/Nm^3 (0.022 to 0.035 gr/ft^3), well within the German limit of 100 mg/Nm^3.

The testing was done by Dr. Reimer of "P. Goepfert and H. Reimer" in Hamburg and Professor Zinn of the University of Hamburg. It is assumed that the test method used followed the TUV procedure which is the standard in Germany.

Zurich: Hagenholz

The Martin boiler-furnace unit at Hagenholz, Unit No. 3, is equipped with an Elex precipitator having a maximum gas flow rate of 95,580 Nm^3 (56,200 scfm) assuming that the refuse lower heating value is 2800 kcal/kg (5040 Btu/pound) and that 11,800 kg per hour (13 tons per hour) are burned. The mean velocity is 0.814 m/sec. (2.67 f/s) The furnace/boiler emits flue gas with 2500 mg/Nm^3 (1.09 gr/scf) of particulate.

The Elex ESP has a cross-sectional area of 74.1 m^2 (797 ft^2). The effective surface collection area is 3560 m^2 (38,306 ft^2).

Elex felt that it has enough experience and a flow-model study was not performed. Mr. Erick Moser, the technical assistant lamented that, "There is never enough information on (inlet) gas and dust composition."

Flue gases must pass through a perforated plate and a series of baffles before entering the electric field. The output voltage is 78 kv with an effective output curent of 2,430 ma.

The unit is cleaned by mechanical rapping with a hammer. Flyash falls through pyramidal hoppers and is removed by a feedscrew.

The insulation is 80 mm (3.1 in) thick. In the winter, the hopper is electrically heated.

The flue gas temperature entering the ESP is usually 280 C (536 F). If it rises to above 300 C (572 F), there is serious danger of high temperature corrosion from chloride attack. The chloride attacks the steel until it becomes spongy and short circuits become common.

Plant staff cautioned against closing the plant on weekends. They have observed other plants that develop dew point corrosion at the 150 C (302 F) flue gas temperature level. When this boiler-furnace is shut down eight (8) hours for the 1000 hour planned inspection, the ESP is kept warm by the 150 C (302 F) steam from the oil-fired stand-by boiler. The ESP is thus cooled only twice per year - during the 4000 hour planned inspections.

Whenever the input voltage falls below 78 kv and cannot maintain a 65 kv charge across the fields, then operators know that excessive short circuiting is occuring and that inspection and maintenance should soon follow.

When Units No. 1 and 2 were built at Hagenholz in 1969, the Swiss air pollution law limited emissions to 150 mg/Nm^3 corrected to 7 percent CO_2 but the Zurich request for proposals specified a 100 mg/Nm^3 limit (0.0435 gr/scf). The two-field Elex ESP followed by the Rothemuehle multi-cyclone more than met the requirements and average 70-90 mg/Nm^3 during compliance tests. The original compliance test for one of the first units produced the following:

Units No. 1 and 2		
Particulates - total	72 mg/Nm^3	0.03 gr/scf
Particulates - over 30 um	15 mg/Nm^3	0.006 gr/scf
CO_2	7.7 percent	--
O_2	9.2 percent	--
H_2O	15.7 percent	--
SO_2	219 mg/Nm^3	76 ppm
HCl	531 mg/Nm^3	331 ppm

Later, after the units had been operating over the critical 300 C (572 F) limit, corrosion began and later readings changed to 120 mg/Nm (0.052 gr/scf). As a result Units 1 and 2 were derated to lower firing rates. When Unit No. 3 was built in 1973, the regulation had been tightened to 100 mg/Nm^3 for particulates. The RFP thus specified 75 mg/Nm^3. During the compliance test, conducted by EMPA, an excellent reading of 42 mg/Nm^3 (0.018 gr/scf) was recorded. Assuming an inlet loading of 2500 mg/Nm^3 and an output reading of 42 mg/Nm^3 means that the unit operates at an efficiency of 98.3 percent.

Unit No. 3	SI Units	Eng. Units
Particulates - total	42 mg/Nm^3	0.018 gr/scf
CO_2	8.4 percent	--
H_2O	12.0 percent	--
SO_2	220 mg/Nm^3	82 ppm
HCl	840 mg/Nm^3	560 ppm
HF	11 mg/Nm^3	13 ppm
ZnO	4.7 mg/Nm^3	0.002 gr/scf
Pb	0.37 mg/Nm^3	0.0002 gr/scf

Now that the third generation Josefstrasse is being built (Martin is the designer), the RFP specification has been tightened further to 50 mg/Nm^3 (0.022 gr/scf). As of this writing, the plant is under construction and thus no compliance test has been made. Officials have been so pleased with the Elex precipitator at Hagenholz (marketed by American Air Filter in the U.S.), that it was easily chosen for the next plant at Vosefstrasse.

The Federal Switzerland Government had a financial incentive program several years ago that motivated construction of many refuse fired steam generators. A condition for the Federal money was that the plant pass its compliance test. Prior to passing the test, vendors would have to wait for their money or the city would have to obtain a short term bank loan. This policy has done much to ensure plants with well controlled emissions. The program still exists on paper, but funds have not been nearly as plentiful as in years before. In many Swiss regions there has been overbuilding of these plants and several persons have mentioned that Switzerland is "saturated" with RFSG's.

The Hague

Each of the 4 units at the Hague is equipped with an electrostatic precipitator. Those for Units 1-3 were made by a Swedish company. No. 4 was built by Rothemuhle of West Germany. Gas flow rate is 90,000 Nm^3/h (52,965 scfm).

There are two electrical fields per precipitator. Preliminary model flow tests were made for the Unit 4 precipitator only. Average velocity is 2 m/sec (6.5 fps). Entering flow is distributed across the passage by a perforated plate. There are 204 plates per field, each 7 m by 0.3 m (23 ft by 1 ft). Plate spacing is 0.3 m (1 ft). Cleaning of the plates is by mechanical rapping. Rectifier output is 40,000 volts with 15 cm (6 in) of insulation but are unheated. The hopper for Unit 4 is heated electrically. The collected ash is sluiced to a flyash setting tank.

The precipitators for Units 1-3 were guaranteed to achieve an emission level of 100 mg/Nm^3 (0.0437 gr/scf) corrected to 7 percent CO_2. They have been tested twice in ten years. The last showed an emission of only 55 mg/Nm^3 (0.024 gr/scf). Unit 4 was guaranteed for 80 mg/Nm^3 and in September 1974, when tested emitted only 19 mg/Nm^3 (0.008 gr/scf). Its efficiency was stated to be 99.6 percent with two fields and 85 percent with one field.

The refuse burned in Units 1-3 had a much higher heat value than expected, with the result that there were times when the gases leaving the economizers were as high as 330-350 C (626-662 F), far above the safe operating temperature for the precipitators. As a result, the plates rapidly corroded and had to be replaced. Because of that experience the temperature entering the precipitators is now held below 270-280 C (518-536 F). When the economizer exit temperature begins to exceed about 225 C (437 F) plans are made to clean the boiler heating surfaces. These practices have almost eliminated plate corrosion.

Some corrosion has been found near the top of the last field caused by excessive temperatures. Attempts are made to hold it to 250 C (482 F), but at times it reaches 300 C (572 F). Hopefully the planned installation of additional heat absorbing surface in the second pass of the boilers will help to reduce the precipitator temperature.

Dieppe-Deauville

Flue Gas dust is removed from Dieppe gases by a vane-type 56-tube, multiple cyclone separator following each boiler built by Louis Prat of Paris. The design flow rate is 22,000 Nm^3 hr (12,940 scfm). Initial gas temperature was 350 C (662 F) but after secondary air jets were added in the front wall, it dropped to 280 C (536 F). Pressure drop at 350 C (662 F) is 62 mm water (2.4 in) 608 Pa. Figure X-4 shows a 155 mm diameter cast alloy vane for imparting spin to the gases entering each of 56 collector tubes in the dust collector. It is warranted to collect 92 percent of the dust, giving an emissin of 400 mg/m^3 (0.17 gr/scf at 450 C) (842 F). The initial measured emission was 320 mg/Nm^3 (0.27 lb/1,000 lb gas) (0.14 gr/scf). This emissin rate would not comply with many current emission limits for particulates.

The collected dust falls continuously through a lock chamber controlled by two cam-operated cast iron flap valves into a screw which discharges it to the grate residue quench channel. The staff are well aware that failure to keep this lock chamber gas-tight will allow reentrainment of the collected ash with consequent vane and collector tube erosion. The flap valves are serviced every 6 months to assure their tightness.

The newer plant at Deauville does not have a multicyclone but uses instead an electrostatic precipitator which has an inherently higher collection efficiency. It was designed for an emission rate of 150 mg/Nm^3 (0.06 gr/scf). When handling a volume of 20,000 Nm^3 hr (11,760 scfm). The Dieppe and Deauville plants meet the French emission limits for particulates which are on a sliding scale as shown earlier in Table X-2. After neighbors complained about noise from the plant, a noise silencer was placed on top of the stack as shown in Figure X-5.

Gothenburg

The 3 units at Gothenburg, each rated at 12.5 tonnes/hr (13.8 ton/hr) are served by three electrostatic precipitators built by Svenska Flaktfabriken, each has a design flow rate of 100,000 Nm^3/hr (58,850 scfm). Flow model test were not used in the design. Average velocity was 1.15 m/sec (3.8 fps). Particle residence time was 4.8 sec. There are two fields.

When the precipitators were tested in 1973, the guaranteed emission limit of 150 mg/Nm^3 (0.06 gr/scf) corrected to 10 percent CO_2 was exceeded. Accordingly, the manufacturer provided an additional smaller precipitator along side the three others to which a portion of the gas is bypassed. The result is lower velocity, longer residence time, and the combination now meets the 150 mg/Nm^3 design limit. Regulations require that the precipitators be tested twice per year.

Some corrosion has been found near the top of the last field caused by excessive temperatures. Attempts are made to hold it to 250 C (482 F), but at times it reaches 300 C (572 F). Hopefully the planned installation of additional heat absorbing surface in the second pass of the boilers will help to reduce the precipitator temperature.

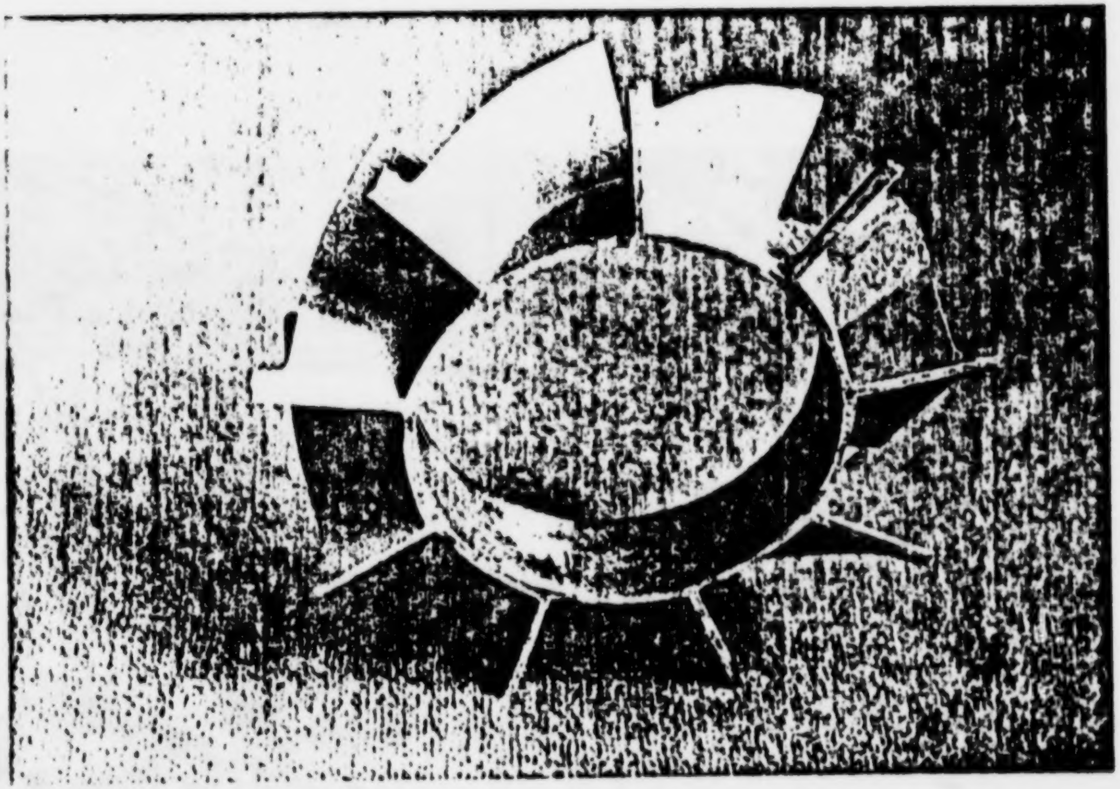


FIGURE X-4. REPLACEABLE CAST ALLOY STEEL VANE WHICH IMPARTS SPIN TO THE GASES ENTERING EACH COLLECTION TUBE OF THE PRAT MULITPLE CYCLONE DUST COLLECTOR (Battelle Photograph).

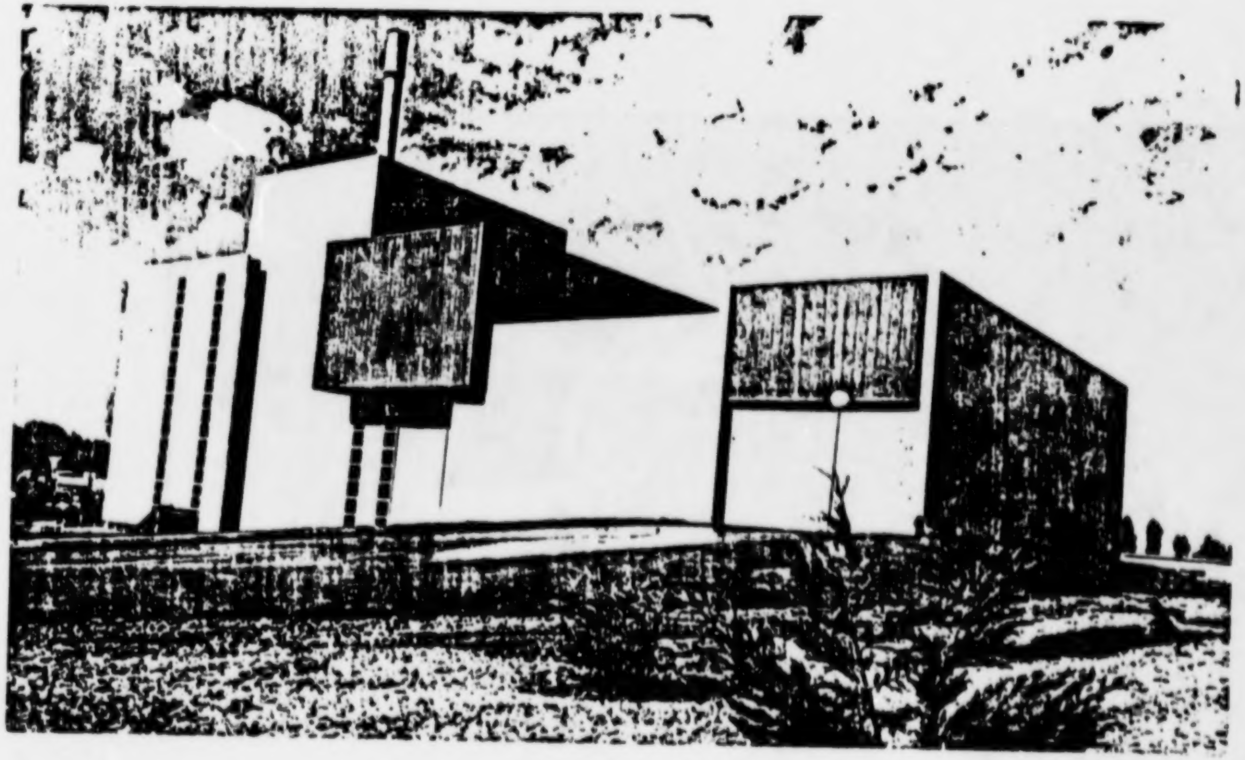


FIGURE X-5. DEAUVILLE REFUSE-SLUDGE COFIRING PLANT
(COURTESY OF INOR S.A.)

Uppsala

Originally in 1962, the Uppsala plant had only mechanical dust collectors for air pollution control. Then at the time the fourth furnace was installed in 1970, two electrostatic precipitators were installed serving all furnaces, as shown in Figure X-5. An unusual feature of Precipitator No. 1, serving Furnaces No. 1 through 3, is that it is followed by a multiple cyclone dust collector due to concern that large flakes of charred paper would escape the precipitator. There are 200 cyclones, each 200 mm (7.9 in) in diameter. However, similar cyclones were not included in Precipitator No. 2 because centrifugal action of the Bruun and Sorensen after-combustion chamber which follows No. 4 furnace usually breaks and burns any such large flakes before they reach the precipitator.

Table X-8 shows the results of performance tests on No. 2 precipitator servind Furnace No. 4 in 1972. The resulting particle emission rate of 15 to 38 mg/Nm^3 (0.0066 to 0.017 grains/scf) is well within the Swedish (Statens Naturvardsverk) standard of 85 mg/Nm^3. Table X-8 shows later measurements of gaseous emissions from the original three furnaces.

The second precipitator has required almost no maintenance. Only one electrode has needed replacement in 5 years. There is some wet corrosion of the steel expansion joints in the long duct leading outdoors from the precipitators to the chimney. These joints have, therefore, been replaced by heavy-coated nylon fabric. However, in the precipitator serving the first three boilers, 100 electrodes have been replaced since 1971 due to corrosion.

The dust hoppers are heated and when the system is not operating, a fan circulates air in the hoppers to prevent moisture buildup.

Figure X-7 shows the exterior of Precipitator No. 1. Figure X-8 shows the ducts leading the exhaust gases to the ten-flue chimney.

Horsens

At Horsens some flyash is removed mechanicaly in the cyclonic after-combustion chamber. The partially cleaned gases are then cooled in the boiler and pass to an electrostatic precipitator built by Svenska Flaktfabriken according to the general specifications as follows:

Flow rate:	36,000 Nm^3/hr (21,186 scfm)
Entering temperature:	
With spray cooler	300 C (572 F) (Prior to 1977)
With boiler	220 C (428 F) (After 1977)
Dust load (at 10 percent CO$_2$):	
Entering	5 g/Nm^3 (2.194 gr/scf)
Leaving (max)	180 mg/Nm^3 (0.078 gr/scf)
Rectifier	50 kv. 800 ma
Precipitator volume	134.4 m^3 (4,730.9 ft^3)
Average flow area	21 m^2 (226 ft^2)
Velocity at stp	0.48 m/sec (1.6 fps)

The precipitator design was preceded by a flow model study which was deemed essential because of the complicated flow patterns produced by the combined flow of gas partially from the spray cooler and partially from the sludge dryer. In March, 1977, it was tested twice by the Horsens Levendsmiddellaboratorium (Environmental Laboratory, formerly the Veterinarian and Food Lab). The emission results were 165 and 178 mg/Nm^3 corrected to 10 percent CO$_2$.

The outdoor precipitator is insulated with 100 mm (4 in) of rockwool encased in aluminum. Mechanical rapping is provided for both

Manoverrum - Control Room
UGN.2 - Furnace 2
UGN.3 - Furnace 3
UGN.4 - Furnace 4
(UGN.1 is connected by a duct to steam boiler AP 1)
AP 1 - Boiler 1
AP 2 - Boiler 2
AP 3 - Boiler 3
7 & 8 Electrostatic Precipitators

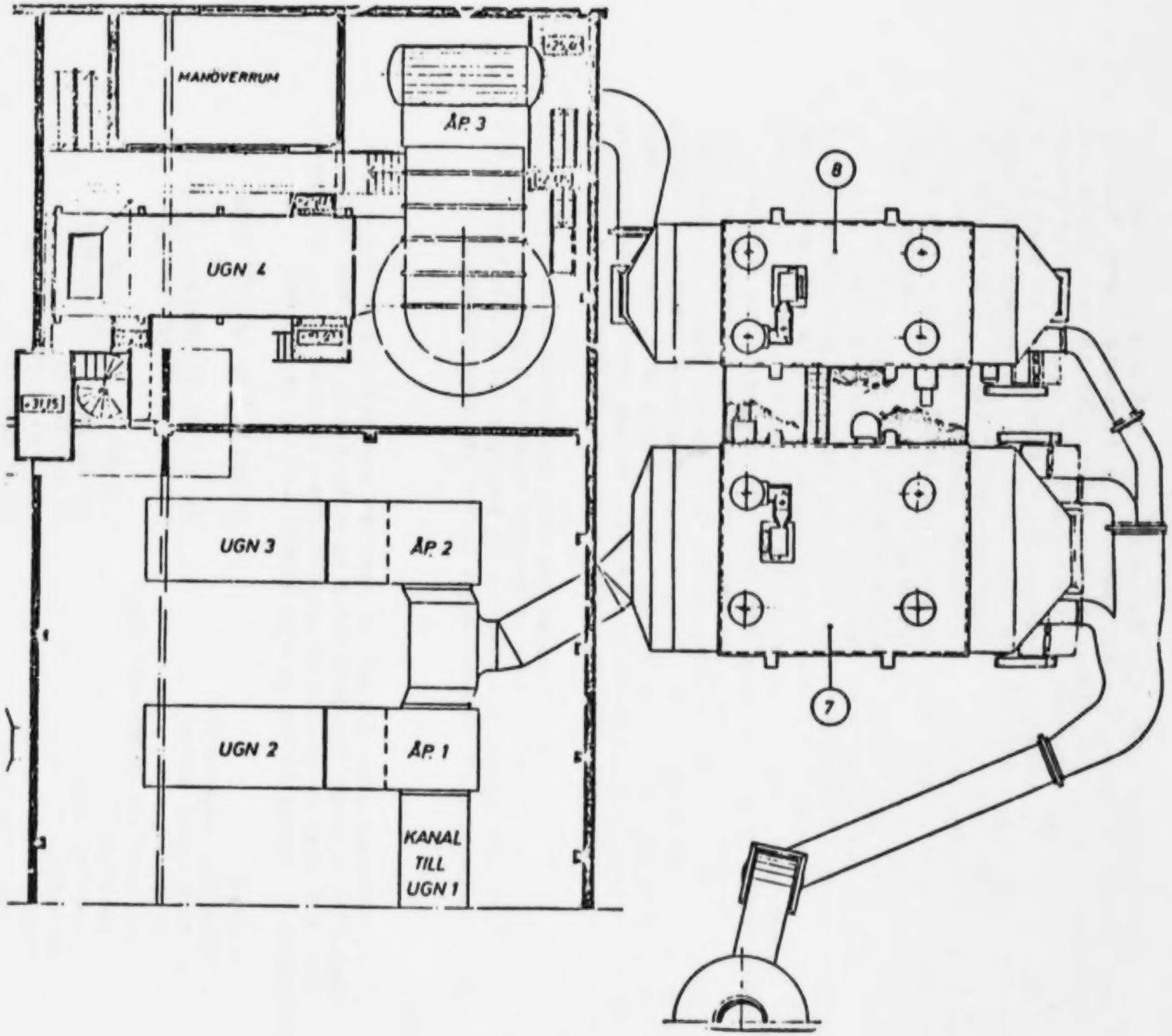

MANOVERRUM
ÅP 3
+25,6
8
UGN 4
+31,15
UGN 3
ÅP 2
UGN 2
ÅP 1
KANAL
TILL
UGN 1
7

FIGURE X-6. ARRANGEMENT OF COMPONENTS OF BOLANDER INCINERATOR PLANT AT UPPSALA (Courtesy of Uppsala Kraftvarme AB).

TABLE X-8. PERFORMANCE TEST DATA ON PRECIPITATOR NO. 2 SERVING FURNACE NO. 4 (COURTESY OF UPPSALA KRAFTWARME, AB)

	Test 1	Test 2	Test 3
Date (1972)			
Time of Day	8:08 a.m.- 9:41 a.m.	11:00 a.m.- 1:46 p.m.	2:51 p.m.- 4:30 p.m.
Waste Burning Rate, kg/h	4,560	4,560	4,560
Steaming Rate, kg/h	11,500	15,100	14,900
Gas Flow Rate, Nm^3/sec	8.13	8.13	8.13
Gas Flow Rate, Nm^3/hr	29,300	29,300	29,300
Gas Flow Velocity, m/sec	0.71	0.71	0.71
Gas Temperature in Precip., C	205	208	208
Gas Temperature before Precip., C	210	216	218
Moisture, Volume Percent	--	13	11
Humidity, Percent	--	0.7	0.6
Dew Point, C	-	51	48
CO$_2$ Leaving Boiler, Percent	7.5	9.9-10.1	9.3-9.4
CO$_2$ Entering Precipitator, Percent	8.0	9.7	8.0
Draft After Boiler, mm Water	58	70	69
Damper Position, Percent	35	36	34
Precipitator Voltage, kv	31.7	33.5	32.5
Plate Current, mA/m^2	0.33	0.33	0.33
Primary Current, A	55.7	55.7	55.8
Dust Loading			
Wet Gas, Entering, g/Nm^3	0.694	0.815	0.687
Wet Gas, Leaving, g/Nm^3	0.013	0.017	0.034
Dry Gas, Entering, g/Nm^3	0.789	0.937	0.772
Dry Gas, Leaving, g/Nm^3	0.015	0.020	0.038
Collection Efficiency, Percent	98.13	97.91	95.06
Dust Collection Rate, kg/h	22.9	22.9	22.9

TABLE X-9. RESULTS OF GASEOUS EMISSION MEASUREMENTS FROM ORIGINAL THREE FURNACES AT UPPSALA (APRIL 23, 1974) (COURTESY UPPSALA KRAFTVARME AB)

Test Number	1	2	3	4
Time, a.m., p.m.	9:00-9:45	9:57-10:47	11:00-11:48	12:---12:45
Steam Production Rate, tonnes/hr	22.4	22.4	22.4	23.9
Gas Volume Sampled, Nm^3	0.106	0.111	0.078	0.103
CO_2, Percent Dry Gas	6.4			
O_2, Percent Dry Gas	10.4			
SO_2, mg/Nm^3, Dry Gas	110	110	210	60
SO_2, mg/Nm^3, corr. to 10 Percent CO_2	170	170	330	90
HCl, mg/Nm^3, Dry Gas	73	79	34	14
HCl, mg/Nm^3, corr. to 10 Percent CO_2	114	124	53	22

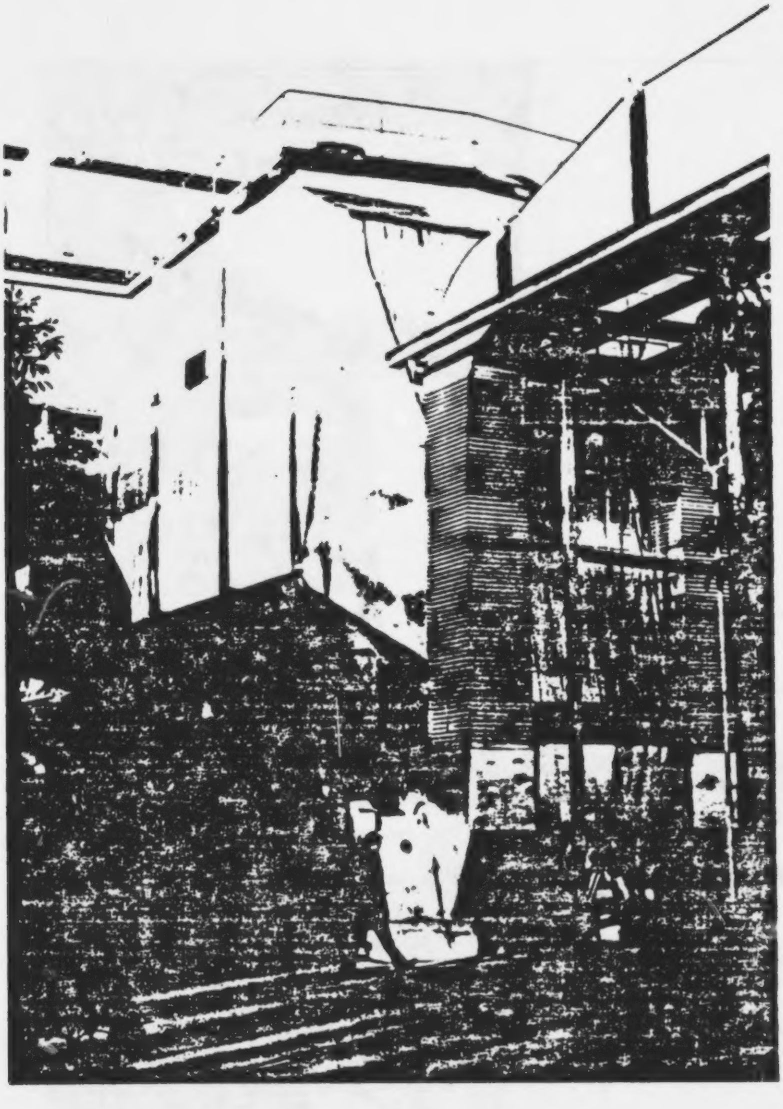


FIGURE X-7. ELECTROSTATIC PRECIPITATORS RETROFITTED FOR UNITS #1 AND #2 OUTSIDE AT UPPSALA (Battelle Photograph)

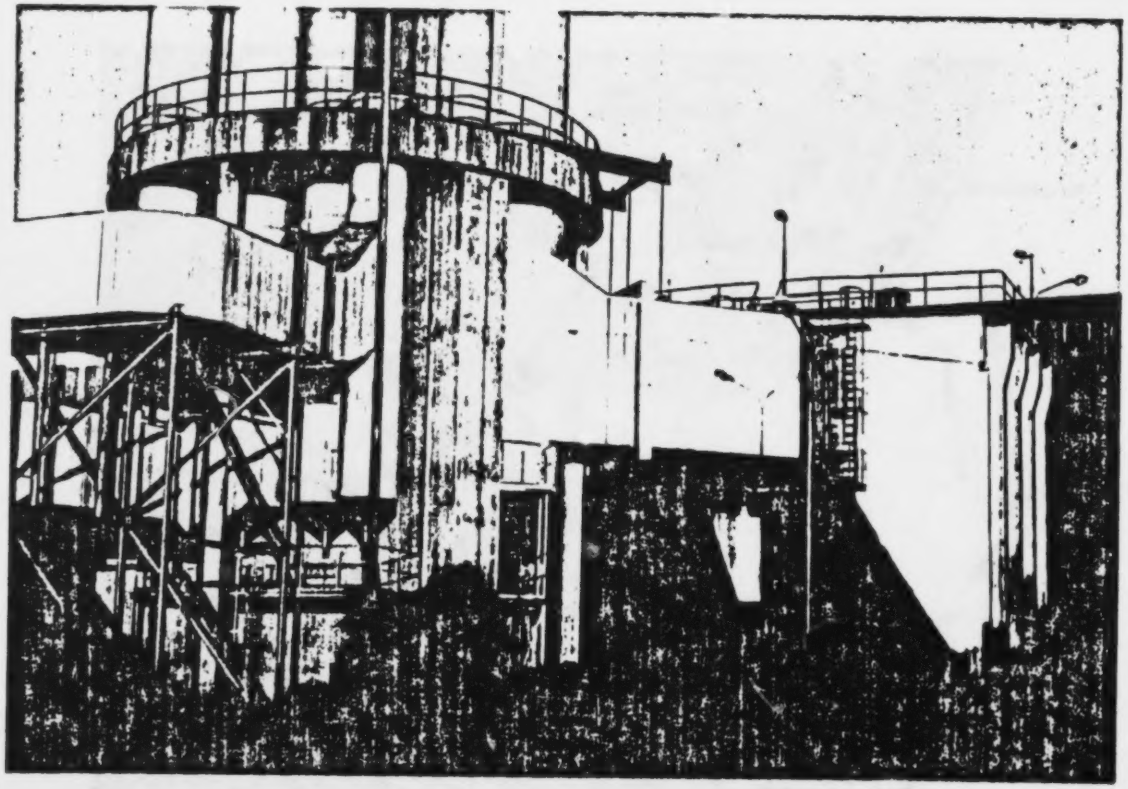


FIGURE X-8. DUCTS LEADING TO BASE OF TEN FLUE CHIMNEY AT UPPSALA (Battelle Photograph)

charging electrodes and collector plates. The collection hoppers are electrically heated to prevent condensation.

The flyash is removed from the hoppers by a Redler conveyor. At first, the dry flyash was added to the wet grate residue but that produced intolerable dust. Then the flyash was mixed with the sludge leaving the drying kiln but a chemical reaction occurred. Now they are attempting to form clinker with the sludge in the kiln. If the metal content is not high, it might have some value as soil nutrient. Tests by the environmental laboratory have established that the flyash is not harmful if ingested by animals.

The plant staff are well pleased with the precipitator performance as it has required minimal maintenance, although they observe that some degradation of collection efficiency has occurred in 4 years of operation.

Copenhagen: Amager and West

Both at Amager and West, Rothemuhle two field electrostatic precipitators (ESP) are the sole means of air pollution control now in effect. Plant officials were hesitant about this and had thought of the need to add a mechanical cyclone collector after the ESP. They wanted to make sure that the larger paper particles would for certain be captured. Therefore, they mandated that room should be available for adding the cyclones later if necessary. The space is outlined with dash lines in the previous Figure X-10. As discussed later, there has been no need to add any cyclones.

The ESP inlet gas flow is 107,000 Nm^3/hour (62,916 scfm). The temperature is designed to be around 300 C (572 F) with a 350 C (662 F) maximum. Because of the clogging economizer section of the boiler, there have been many excursions well above 350 C (662 F). As a result, there has been some corrosion at the top and front end of the ESP. Volund estimates the inlet loading to be 7.5 g/Nm^3.

Flow-model studies were not conducted before installation. The average flow velocity is 0.86 m/sec (2.8 ft/sec). The maximum is 1 m/sec (3 ft/sec). Each ESP field has two rectifiers. Volund would permit a one-field ESP only on a small system where the regulations are not as stringent. A Volund brochure describes their system as follows:

> "In the electrostatic filter the speed of the smoke (gas) is reduced to approximately 1 m/s, after which the smoke passes between vertically suspended, electrically earth connected profiled steel sheets. The mutual distance between the sheets is about 25 cm. Tightly stretched between the sheets are a great number of steel wires, equipped with spikes. The steel wires are insulated when hung and are connected with an 80,000 volt direct current generator. When the smoke slowly passes this system of negatively charged steel wires, the dust particles carried along will be electrically charged and will therefore be pulled over onto the earth-connected (grounded) sheets. Thus, a continuous layer of dust will gradually be formed on the sheets and can be shaken off by hard blows on the sheets. This causes the lumps of

FIGURE X-9. LOOKING OUT THE WINDOWS TAKEN FROM UNDER THE ELECTROSTATIC PRECIPITATORS AT COPENHAGEN: WEST

Reproduced from best available copy.

dust to drop into accumulation funnels from which the dust is removed by means of an automatic transport system, is moistened, and sent to the slag pit.

"The total efficiency of the electrostatic filter is more than 98 percent. During 1972, approximately 5,000 tons of flyash was separated through Amagerforbraending's filters."

Even though the ESP is housed inside the normally warm furnace/boiler room, the ESP hoppers are equipped with electric heaters. When the room temperature falls to 10 C (50F), the heaters are turned on to prevent possible dew-point corrosion in the ESP.

Flyash is removed from the bottom of the ESP hoppers pneumatically. The pneumatic tube dumps onto a conveyor belt for transport to the ash bunker.

Upon startup, the unit exceeded the 150 mg/Nm^3 limit for particulates. The primary reason was that a standard ESP (without special entrance vanes) was used to clean a very highly loaded flue gas. The Amager estimate of 7.5 g/Nm^3 compares with more typical inlet loadings of around 5 g/Nm^3. The action of the rotary kiln generates higher dust loadings.

Because of noncompliance, Rothemuhle responded to its guarantee. They then did conduct flow model tests. Turning and guide vanes were added. The tests proved so successful that they again concluded that cyclones would not have to be added.

The new Danish air pollution regulations specify limits for particulates, HCl, and SO_2 (corrected to 11 percent O_2 and 7 percent CO_2). Amager tests show that the unit is now well within the limits.

	Danish Law	Design of Actual Amager Plant
Particulates (mg/Nm^3)	150	60 - 90
HCl (mg/Nm^3)	1,500	700 - 900
SO_2 and SO_3 (mg/Nm^3)	1,500	200 - 300

Because of the HCl and SO_2 gases are in compliance, no scrubber has been needed. A new feature of the law is that particulate tests are to be made every month. The sampling point is 50 m up the 150 m chimney. The respected Danish Boiler Testing Company is employed to perform the tests.

One emissions analysis reported is as follows:

Nitrogen (N_2)	66.40 percent
Oxygen (O_2)	12.40 percent
Carbon Dioxide (CO_2)	12.40 percent
Water (H_2O)	8.64 percent
Hydrogen Chloride (HCl)	0.06 percent
Sulfur Dioxide (SO_2)	0.01 percent
Unidentified and Measuring Errors	0.09 percent
TOTAL	100.00 percent

Volund officials repeated a statement heard elsewhere in Europe and America that, "for each 1 percent above 96 percent efficiency, the ESP urchase price doubles". This, is only a crude approximation. However, it makes the clear point that going from clean air emissions to very clean air emissions is very expensive.

Volund is also considering a modest sized spray chamber before the ESP. The added moisture should improve the particle's action when on the electrodes by reducing particle resistivity.

As the result of a study, flyash is not mixed with botton ash so that the bottom ash can be recovered and used as "non-cementing" gravel.

The Danish regulation for particulates is 150 mg/Nm^3 corrected to 11 percent O_2 and 7 percent CO_2. At West the so corrected reading was well within limits at 90 mg/Nm^3. The Danish Boiler Testing Company made the measurements. It was such an expected low actual reading that caused Rothemuehle not to put in the cyclone collector. However, if the reading were higher, Rothemuehle (at its expense) would have had to install the cyclone.

Stack Sampling Methods

Because the measured performance of pollution control equipment is so crucially dependent upon the measurement methods used an effort was made to learn the details of the measurement procedures used. In many cases the plant staff were unfamiliar with the exact methods used because the tests are usually conducted by an outside agency which specialized in emission measurements. A notable exception was at the Issy-le-Moulineaux plant at Paris which is operated by the Service du Traitment Industrial des Residus Urbans (TRIU). TRIU is a profit oriented division of the state-owned electric utility Electricite de France. TRIU has a trained three-person sampling team which tests each precipitator about once per month. Figure X-10 shows the sampling system used. The flue gas is sampled for 10 minutes at each point up to about 48 points, depending in the size of duct and local circumstances. Not only does this team sample TRIU plants but they are available and do some contract sampling for other facilities. Four obvious advantages of having such a regularly working team for emissions measurements are:

1. The team is kept active and skilled for this difficult and demanding task which is often neglected if carried on as an infrequent, part-time activity.
2. The plant operator has frequent data showing where the plant stands regarding compliance with applicable limits.
3. If equipment deterioration occurs the management is alerted for corrective action before the condition reaches a crisis stage precipitating possible complaints from neighbors.
4. The regular updating of plant emission records is useful in informing environmental control groups on the long term and short term performance of the pollution control equipment.

Earlier in this section on Control Equipment, Table X-7 showed the results of gaseous and particulate emission tests using this method at Issy on four different days in February 1977. All of these tests showed particulates to range from 36 to 59 mg/Nm^3 well within the required 80 mg/Nm^3 at 7 percent CO_2 (the equivalent of 137 mg/Nm^3 at 12 percent CO_2, 0.06 gr/scf), although the boiler load and exit temperature varied widely, indicating considerable variation in fuel-bed burning conditions.

In West Germany a similar particulate sampling system is used as shown in Figure X-11. This is prescribed in considerable detail in

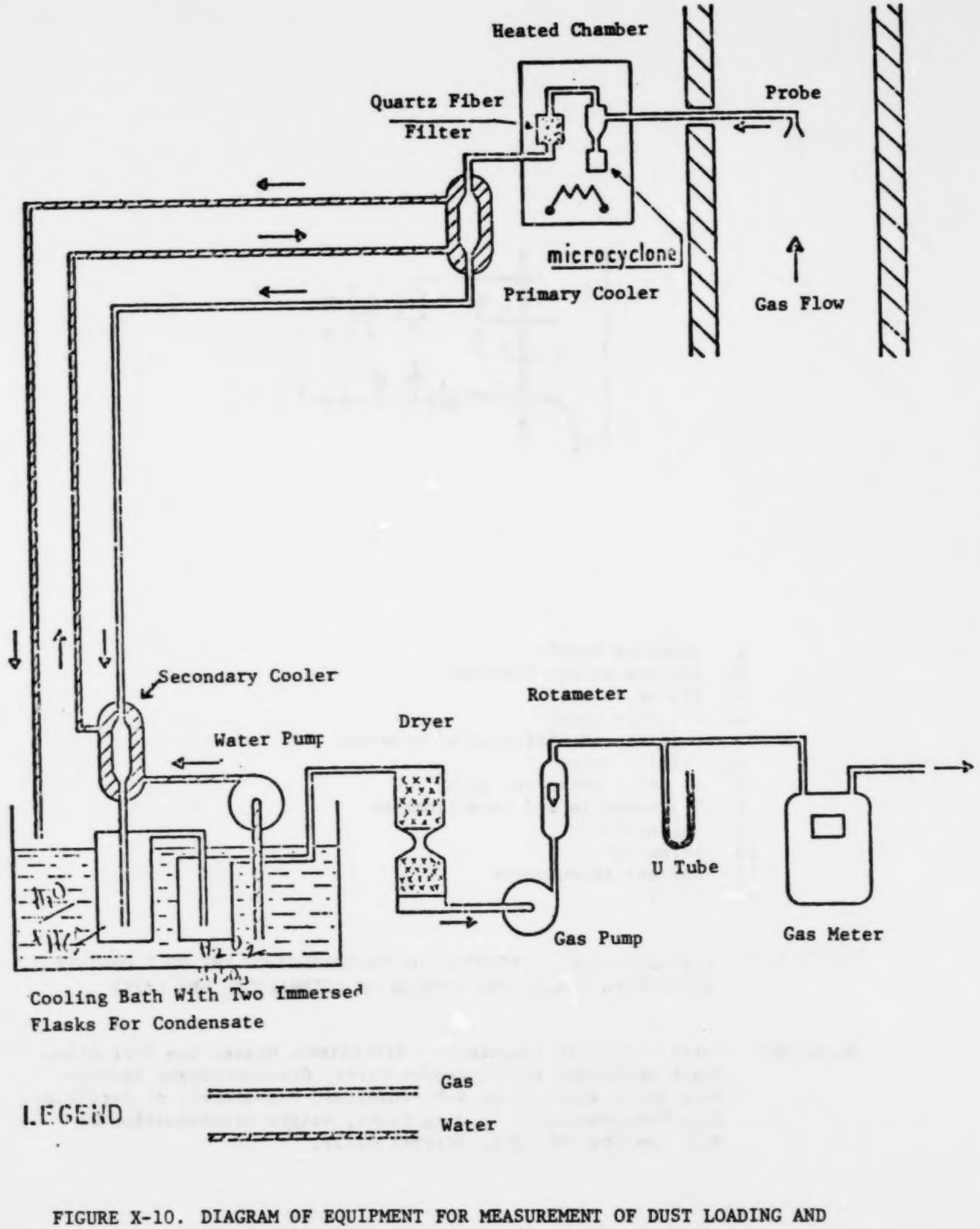
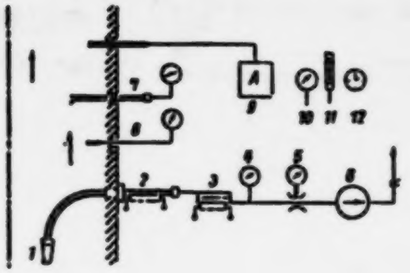

Heated Chamber
Quartz Fiber
Filter
Probe
microcyclone
Primary Cooler
Gas Flow
Secondary Cooler
Rotameter
Dryer
Water Pump
U Tube
Gas Pump
Gas Meter
Cooling Bath With Two Immersed
Flasks For Condensate
LEGEND
Gas
Water

FIGURE X-10. DIAGRAM OF EQUIPMENT FOR MEASUREMENT OF DUST LOADING AND MOISTURE CONTENT OF A GAS. (Courtesy of TIRU)



1. Sampling nozzle
2. Suction probe (heated)
3. Filter (heated)
4. Pressure gage
5. Orifice and differential pressure gage
6. Suction pump
7. Velocity probe and gage
8. Thèrmocouple and potentiometer
9. Gas analyzer
10. Barometer
11. Ambient thermometer
12. Clock

FIGURE X-11. APPARATUS FOR ISOKINETIC DETERMINATION OF THE DUST CONTENT OF FLOWING GASES (VDI KONMISSION REINHALTUNG DER LUFT)

REFERENCE: Verein Deutsche Ingenieure - Richtlinen, Messen Von Partikeln, Staub Messungen In Stromenden Gases, Gravimetrische Bestimmung der Staubbeladung (VDI-Guidline, Measurement of Particles, Dust Measurement In Flowing Gases, Weight Determination Of Dust Loading VDI 2066, October 1975).

Guideline Number 2066 (VDI 2066) of the German Society of Engineers (VDI), October 1975 edition.

The sampling methods used in other countries were not learned although it appears that the VDI Guideline is used as a guide in Switzerland and other countries.

In Denmark the sampling is often done under contract by a team from a Danish Technical Group.

START-UP AND SHUT-DOWN PROCEDURES

General Comments

Detailed comments about such procedures were sought at four facilities. Starting up a unit can take anywhere from 2 to 24 hours depending on how much the furnace had cooled from the last firing.

Often a light oil burner is used to preheat the boiler and electrostatic precitptator. A slight variation is that the oil burner is almost always kept on during shut-down to prevent dew point corrosion of the boiler and electrostatic precipitator.

SPECIFIC SYSTEM COMMENTS

Duesseldorf

Start-Up. The following start-up procedure was described by the plant manager, Mr. Thoemen:

- Check all access ports, assure that all workers are outside, that internat equipment appears in order. This check takes 1 hour.
- Preheat the boiler with steam from the intermediate pressure line. This takes 4 to 8 hours.
- Fill the boiler with feedwater and build the pressure to 20 atm (275 psig).
- Adjust the steam flow to blow out any condensate from super-heater and set valve about 40 percent open.
- Start primary air fan at minimum flow, start grate rollers and start hot condensate flow through air prehheater.
- Over the next 45 minutes, complete the following:
  - Fill refuse feedchute
  - Start refuse feeder
  - Cover first two rollers with refuse
  - Light oil burner
  - Increase feed gradually at rate governed by rate of rise of superheat temperature
  - Start flow of steam to Flingern Power Plant.

The total elapsed time for this start-up procedure is usually 8 to 10 hours.

Normal Shut Down.

- Crane stops filling chute.
- Increase furnace draft to maximum.
- Reduce primary air.
- Empty chute onto grate over a period of 2 to 3 hours.
- Complete burnout of refuse on bed over a period of 1 to 1-1/2 hours.
- Stop steam flow to main line.
- Vent steam to intermediate line.
- Continue primary air fan for 4 to 6 hours.
- Turn off fans to allow final cooling by natural draft.
- After 24 hours, begin repair work on unit.

Emergency Shut Down.

- If a tube fails, shut off steam flow to main line.
- Shut off primary and secondary air.
- Extinguish fire with fire hoses.
  - Complete extinguishment takes 5 to 6 hours.
- Turn grate off.
- Stop feedwater pumps.
- Empty grate.

Shared Services. Typically when there is starting or shutdown of any key component at Duesseldorf, the operator fills out any one of several specialized computer cards (See Figure Y-1). These are used in a computer

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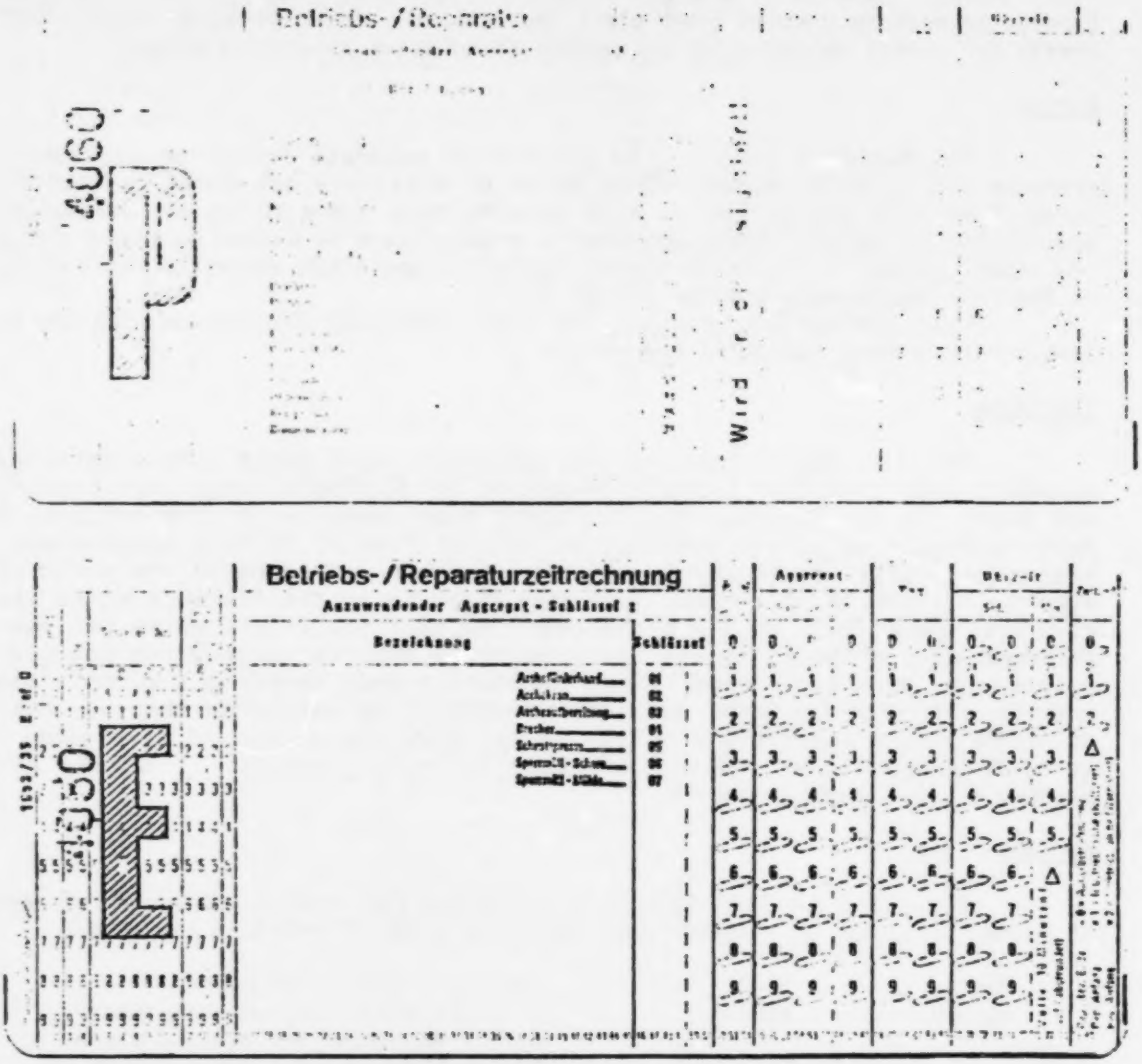
Betriebs-/Reparaturzeitrechnung
4050
Auszuwendender Aggregat - Schlüssel :
Bezeichnung
Schlüssel
Brecher
Aggregat

FIGURE Y-1. SAMPLE DATA CARDS USED IN PLANT DATA
SYSTEM AT DUESSELDORF

program to keep track of operating hours, downtime, etc. Klaus Feindler, technical director of VKW's American licensee, Grumman Ecosystems, points out an advantage of having the refuse system as part of a larger energy system. This computer program was really developed for use at the neighboring Flingern Power Plant. Similarly emergency shutdowns and annual major overhauls can be handled in part by trained power plant technicians. This permits lower staff levels for normal operation at the refuse fired steam generating plant.

Zurich

The Number 2 fuel oil is put into a separate boiler package which produces 150 C (302 F) steam. This helps to eliminate dew point corrosion. Steam from this oil boiler is also used to heat tubes in the air preheater, also to 150 C (302 F). The electrostatic precipitator is turned on after about 1/2-hour. After about 1-1/2 hours, fairly dry ann hiogh calorific value waste is fed into the furnace and the charge is lit.

When the unit is stopped for its 1,000 hour inspection, the ESP is kept hot to prevent dew point corrosion.

The Hague

The Von Roll organization provides each plant with a detailed operating guide including specific procedures for startup to avoid over-heating and damage to the system. At this plant tghe operator is also required to follow established curves showing the rate of rise of furnace temperature, economizer outlet temperature, and steam flow rate. Through-out the period of startup of a unit which normally will take 18-24 hours the operator plots the critical parameters on a startup chart so that the active curve for each parameter is plotted alongside the prescribed startup curve which has been established from experience. Thus, the startup chart serves as a guide to the operator and, when completed, provides a record of any excursions that may have occurred during the process. This is one more indication of Mr. Postma's careful management at this plant that is reflected in relatively low maintenance and operating costs.

Horsens

The plant is down Saturday and Sunday for repairs. The other 5 days of operation is not at a steady pace but is on a varied schedule as follows:

Monday	6:00 a.m.	Startup everey other Monday
Monday	2:00 p.m.	On alternate Monday mornings the boiler and grate are cleaned which delays plant startup until 2:00 p.m. Operation is then continuous.
Tuesday		Operation around the clock.
Wednesday		Operation around the clock.
Thursday	10:00 p.m.	Shut down
Friday	6:00 a.m.	Start up
Friday	10:00 p.m.	Shut down

Thus, of the total of 120 hours in a 5-day week, the plant operates 104 hours one week and 96 hours on the alterante weeks. After Christmas and Easter, the load is such that 7-day, around the clock operation is required.

On weekend shutdowns, the induced draft fan is kept operating at a low rate to keep the system ventilated and dry. The refractory setting remains warm so that at the time of startup Monday morning thhe air flow entering the boiler is still about 400 C (752 F).

6

APPENDIX

7

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FOR

SPEC REPTS 1 & 2

(These references are also listed
at the point of use in the
individual chapters.
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here for easy access.)

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Renholdnings Selskabet
Since 1898
Forlandet, 2300 Kbh. S
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Copenhagen
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Danish Boiler Manufacturer's Association

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Waste Management, Inc.
900 Jorie Boulevard · Oak Brook, Illinois 60521 · 312/654-8800

July 30, 1979

U.S. Environmental Protection Agency
Resource Recovery Division A-W 462
Washington, D.C. 20460

Attention: David B. Sussman

Re: Contract No. 68-01-4376

Dear Mr. Sussman:

We at Waste Management, Inc. appreciate being given the opportunity to review the draft of the extensive report prepared by Philip Beltz and his staff at Battelle.

Prior to offering our comments, two statements must be made and accepted. Firstly, that Waste Management, Inc., through its license agreement with Volund, is committed to the concept of mass-burning of municipal refuse using refractory-walled furnaces, and is thus necessarily biased in its judgement, and secondly that the Battelle staff, while having spent a considerable period gleaning information from the constructors and operators of energy conversion plants, have nevertheless colored the content of the report to reflect their own conclusions and opinions. No one can inspect so many operations without developing a preference for a certain system and certainly the editorialising and definitive statements within the report reflect this.

Insofar as the folks at Battelle have been contracted to do just this, it would be inappropriate to argue with their preference, except where statements made in the text are either incorrect or need considerable qualification. This is where we have tried to be of assistance in rendering this report to be the valuable, accurate reference book that it should be.

Specifically, our comments are these:

Ref. p. A.1. par. 3 and 5. "The early units were refractory-walled and thus the steam quality (temperature and pressure) was limited." and "the water-tube wall furnace/boiler" has the refuse combustion section surrounded by vertical or sloping steel tubes in parallel.......generate a major fraction of the steam produced. This increases efficiency and allows a much higher quality steam to be produced.

Steam is generated by the transfer of heat from flue gas (the product of the refuse combustion) to water, via the metal walls of boiler tubes. The efficiency of the boiler is a function of the gas flow pattern and the tube metal surface area. The quality of steam produced is determined by the feed-water pressure, tube wall thickness and location and size of the superheater.

Whether a furnace utilizes a refractory-walled or water-walled combustion chamber is of absolutely no consequence in the final quality (temperature and pressure) of the steam.

Most European incinerators incorporate Eckrohr boilers and it is these devices alone which determine the steam quality, not the combustion system.

The question of whether or not there may be advantages from an efficiency point of view between the two systems is discussed in the attached paper written by Gunnar Kjaer of Volund U.S.A.

Ref. p.A.27. The refractory wall furnaces are generally less expensive and would have technical difficulties raising steam temperatures to much above 260C (500F).

Until the nineteen-fifties, refractory-wall furnaces were the major system utilized throughout the world for raising steam, using all fuels from refuse to coal and oil. Steam temperatures and pressures were determined by the design of the boiler alone and are not in any way affected by the nature of the combustion zone construction.

Steam temperatures in excess of 1000°F are commonplace in boilers with refractory walled furnaces.

The major consideration in refuse-fired furnaces is the quality of the flue gas (which is the same regardless of whether refractory or water wall furnace is employed.) When tube-metal temperatures exceed 700°F, extensive chloride corrosion occurs so that a selection must be made between high steam temperatures (and the attendant high turbine efficiencies) or low maintenance costs associated with low-temperature operations.

There is no technical difficulty whatsoever in generating high temperature steam with a refractory-wall furnace. It is simply poor practice, as the repeated failures in operating water-wall units has demonstrated.

Ref. p.A-53. Pit Doors
It is our opinion that this section should also address the common European practice of piling the refuse above the level of the closed doors in order to further utilize the available hopper capacity.

Ref. p.A-58. Kockum-Landsverk was a Swedish company (formerly a licensee of Volund) and is no longer in the incineration business.

Volund is represented in the United States solely by Volund U.S.A. (VUSA), with whom Waste Management, Inc. has a marketing agreement.

Ref. p.A-103 par. 5 and 6 infer a clear division between the capabilities of refractory-wall and water-wall furnace systems.

In fact, some waterwall manufacturers have chosen to offer units generating high-pressure steam, while some refractory wall manufacturers have preferred to offer only low temperature systems. The decision, as discussed in earlier pages, is based soley on economic implications - higher temperature steam means higher tube failure rate and thus higher operating costs regardless of which system is used.

Within Secion B, Gunnar Kjaer of Volund U.S.A. has identified a number of specific errors in the inventory tabulation which are listed below:

The following comments serve to correct some of the inaccuracies in the list of Refuse-Fired Energy Systems. The corrections apply primarily to

Denmark and Sweden, in which countries I have intimate knowledge of the refuse-incineration market. However, it may be assumed that other geographical areas of the world also need further scrutiny before the lists and the book are sufficiently correct to justify publication.

The comments relate to the plants as numbered on the attached copy of the list.

DENMARK

Plant No. 1, 2 and 3 (Aalborg): This is one plant with two lines, installed in the buildings of a former compost producing plant. Line No. 1 was designed and installed by E. Rasmussen in 1968 using a Flynn & Emrich grate design. The technical data given under plant No. 1 are correct. E. Rasmussen incinerator division was acquired by Bruun & Sorensen in 1970. Since 1973, line No. 1 has been on stand-by only. Line No. 2 was designed and installed by Vølund in 1972 and the technical data given under plant No. 2 in the list are correct. Plant No. 3, Aalborg, does not exist, but is a (partly erroneous) duplication of the information under (1).

A completely new plant, Aalborg II, is presently being installed and will be operating in 1980. It is designed, manufactured and constructed by Vølund and will have 2 lines, each 8 M.T./hr. and will produce high pressure hot water for district heating. The building, now near its completion, will have room for a total of 4 lines, each with 10 M.T./hr. capacity.

Plant No. 5 and Plant No. 39 are the same plant. Correct "date begin operation" is 1969. Location: City of Aarhus in an area within the city known as Tilst.

Plant No. 7: Correct name of location: Brøndby. Second line of same capacity begins operation in 1979.

Plant No. 12, Frederiksberg: Heat medium - steam for district heating (each boiler 7.5 t/hr., 12 bar, 190°C, 17000 lbs./hr., 178 psi, 375°F).

Plant No. 14, Gentofte: Heat medium - steam for electricity generation (each boiler 7.5 t/hr., 14 bar, 350°C, 17000 lbs/hr., 210 psi, 660°F).

Plant No. 17, Herning: The first 3 t/hr. line was installed in an existing gas work building and began operation in 1964. It was closed down and demolished in 1971 following the start of operation of the first line of a completely new plant in a different location, Herning II. This new plant had one line, capacity 3 t/hr., to be followed in 1973 by a second line, capacity 4 t/hr.

Plant No. 19 is the same as plant No. 38. Location: Taastrup. Technical data given under No. 19 are correct.

Plant No. 21, Horsens: Capacity 5 t/hr., 120 M.tpd.

Plant No. 26, Nyborg (Kommunekemi): No electricity production, but use of steam for internal use with balance being sold to the hot water district heating scheme via a heat exchanger.

Plant No. 28, Odense-Dalum: Closed down in 1972.

Plant No. 33 and 34 are two lines in the same plant. Technical data are correct. However, the first line, 3t/hr., was installed by B & S in 1970 and the second line, 4 t/hr., was installed by Vølund in 1973.

Plant No. 36 and 37 are two lines in the same builing.

Plant No. 40, Weston: Energy - high pressure hot water for industrial use.

It should finally be mentioned that Danish environmental standards distinguish between plants with refuse handling capacities over and under 5 metric t/hr. For plants handling more than 5 M. t/hr., particulate emission is limited to 0.065 grains/dscf at 7% CO_2. This standard can not be met by the mechanical type filter (multicyclones, etc.) installed in many smaller plants built before the present guide lines were introduced in 1974.

Therefore, many of the smaller plants are restricted, even where duplicate lines have been installed, to operate one line only, at any given time in order to keep hourly throughput below the 5 M.t/hr. limit. This applies to plants No.'s 1, 11, 13, 15, 16, 17, 18, 20, 23, 25, 27, 30, 31, 33-34 and 36-37.

On this basis, daily rated capacity per system for these plants perhaps should be that of one unit.

SWEDEN

Plant No. 1, Boras: Heat medium - steam, 10.3 + 10.3 + 16.5 M.t/hr., 10 bar, 285°C (22700 + 22700 + 36500 lbs./hr., 150 psi, 545°F). Cogeneration of electricity and H.P.H.W. district heating.

Plant No. 8 and 9, Linkoping, are three lines in the same plant.

Plant No. 10, Stockholm-Lovsta: Built by Vølund-Landsverk in 1938. Refractory wall furnace, refuse-fired hot air generator. Plant burns H, C, LI. Capacity: 4 lines each 7.5 M.t/hr. Originally electricity generation. Line No. 5, 12.5 M.t/hr. installed in 1965 by Vølund-Landsverk. In 1968 two lines were fitted with rotary type dryers for thermal drying of non-dewatered, digested sludge. Designer/Manufacturer: AB Torkapparater, Stockholm.

Plant No. 11, Lulea: Duplicate information. For correct information, see plant No. 12.

Plant No. 12, Lulea: Is correct with the following additions: In addition to the production of hot water for district heating this plant uses the combustion gases to dry undewatered sludge in rotary type dryers supplied by AB Torkapparater, Stockholm.

Plant No. 14, Sodra Sotenas: Location in the Gothenburg Archipelago. To the best of my knowledge, there is no energy utlization.

Plant No. 21 and 22, Stockholm-Solna are the same plant: Two lines have been refurbished by B & S as mentioned under Plant No. 22. Total capacity, 3 x 4 Mt/hr.

Plant No. 25, Sundsvall: Steam is used for electricity production and industrial process steam.

UNITED KINGDOM:

Coventry: Unless recent modifications have taken place, no electricty is generated, but steam is used for internal use, driving fans, hydraulic pumps, etc. via individual direct drive steam turbines. In addition, energy is sold for indutrial space heating for the nearby Chrysler car factory.

FRANCE:

Paris-Ivry: The furnace capacity of this plant has been downrated from 2 x 50 M.t/hr to 2 x 40 M.t/hr. following modifications of the water wall furnaces.

Finally, please note that Table A-25 incorrectly informs that Copenhagen Amager and Copenhagen West produce steam.

The succesive sections relate to actual information received from local contacts during the survey, and are beyond our perview to comment.

We would caution, however, that such comments as appear on page X-16; The appearance of the stack plume was extremely clean and attractive and the stack plume was usually invisible. are necessarily subjective and while we do not question the interpretation (on a two day visit with periodic observation) we cannot help believing that these statements color and prejudge actual long-term performance of the systems.

We hope that our comments together with those of our Danish collegues (being sent direct) are helpful to you in finalizing the report.

Regards,

Gunnar Kjaer
President, Volund U.S.A.

PP Peter J. Ware
Director of Engineering
Waste Management, Inc.

cc: Philip R. Beltz
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Please note also the attached comments, Ref. page A-103, paragraph 7.

June 28, 1979

Waterwall Furnaces vs. Refractory Lined Furnaces

The advantages and disadvantages of waterwall cooled incinerators compared with refractory lined incinerators has been debated in Europe for nearly two decades. Prior to the late 50's refuse incineration furnaces were, as a matter of course, built with refractory lined walls. It was widely accepted that the primary purpose of the refuse incinerator was to dispose of refuse. That refuse incineration is best accomplished in a refractory lined furnace has never been disputed. This is because the high heat capacity of the refractory lining keeps the combustion process going, even when charges of low heat value refuse (due to high moisture or high ash content) are fed into the furnace.

The radiation heat from the furnace walls enable the incinerator to handle portions of refuse which are not, in themselves, auto-combustible. The result is the maximization of volume reduction and a residue with a minimum content of putrescible matter and unburned carbon.

The refractory lined furnace was to some extent, perhaps, more necessary in the 40's and 50's than today because of the lower heat value of the refuse at that time and the different composition.

Refuse in the Western industrialized world has changed considerably since the 40's and 50's, in quantity as well as in composition. The ash and putrescible content has been reduced. The considerable increase in refuse quantities that has taken place is, generally, in the form of highly volatile material, i.e. paper and plastic. The result is a much higher overall heat release from each ton of refuse. However, with so much of the heat value tied up with the high volatile matter, the stabilizing effect produced by refractory brickwork in the furnace is desireable in order to burn the less combustible portion.

Another result of the increasing refuse quantities in the late 50's and 60's has been a demand for larger units. In Europe energy utilization from the refuse has been a matter of course ever since the Vølund company built the world's first continuously operating incinerator in Denmark in 1930. This unit produced electricity from the refuse. Vølund and most of its licensees as well as newcomers to the European incineration field have generally subscribed to the idea of heat utilization from the refuse. However, Vølund was for a long time the only company with in-house expertise and experience in both boiler design and manufacture as well as in incinerator design and manufacture.

As a result, most other incineration plant designs have been based on experience gained from boilers for conventional solid fuels and not on experience with solid waste. Thus, we find that these systems tend to reflect primarily traditional boiler design requirements such as:

-- High efficiency

-- High pressure stability, i.e. the ability to withstand the required static pressure on the water/steam side with minimum use of material in boiler tube walls.

-- Good steam quality without water droplets.

Only rarely, however, has adequate consideration been given to the special thermal conditions applicable to the incineration of domestic refuse. This became even more evident as larger incinerator units were required which began to approach the size of small power station boilers.

This has resulted in essentially conventional power plant boilers been constructed with an incineration grate included. Serious corrosion problems have plagued many of these systems along with problems resulting from slagging and sintering of ash and clinker on the boiler surface after only a few years of operation.

Dew point corrosion, in plants with heat utilization is rare in boilers or in auxiliary equipment, i.e. gas ducts, electrostatic precipitators or I.D. fans. The exhaust gas temperature can easily be maintained well above the dew point temperature for the acids and the flue gases.

High temperature corrosion, on the other hand, presents a serious threat to the availability and also to the operational efficiency of the plant.

The reasons for high temperature corrosion are, today, well understood, and it is generally agreed that the following conditions should be avoided:

-- The presence of local streaks of incompletely burnt gases in the gas passages of the boiler.

-- Boiler wall temperatures (metal temperatures) exceeding 350-400° C. (650-750° F.)

-- The presence of a layer of flyash or clinker in a melting phase on the boiler surface.

Recent investigation indicate that the most dangerous conditions are caused when incompletely burned-out gases come in contact with the boiler walls thereby causing fluctuation between oxidizing and reducing atmospheres in the presence of high temperatures and corrosive gases. If these streaks of reducing atmosphere can be avoided then the metal temperature in itself seems less important.

The occurence of melting temperatures in the flyash and clinker layer, too, is often caused by this local combustion of unburned gases raising the temperature locally above the melting point.

It is, therefore, very important to avoid the streaks of reducing atmosphere in the boiler. This problem must be solved before the gas reaches the boiler rather than in the boiler itself.

Despite all efforts to mix the waste properly before it is fired into the furnace, waste remains a very heterogeneous fuel which burns with varying velocities and oxygen requirements. Therefore, local streaks of unburned gases with high carbon monoxide content as well as temperature fluctuations will occur immediately above the grate, despite the presence of excess air. These conditions are further promoted by the very wide grate areas necessary in high capacity incinerators.

Gases only mix effectively when they are of the same temperature. Therefore, the combustion gases must be retained in the combustion zone long enough to ensure that the gases are completely burned out and properly mixed so that a homogeneous oxidizing atmosphere is created prior to entering the boiler.

Vølund's two-way gas system and the special after-burning chamber allows the time, temperature and turbulence necessary for complete combustion of the gases before they enter the boiler.

The flyash particles consist mainly of easily meltable clinker, which remain "soft" down to a temperature of approximately 600° C. (1100° F.). Even after the surface of the flyash particles is cooled below that temperature, the center remains soft for some time, increasing the risk of the particles sticking to the boiler surface when they flatten on impact.

The degree of clinker slagging and sintering is often the decisive factor in determining when an incinerator must be taken out of operation for maintenance. Therefore, it is important that flyash particles are burned out completely and are effectively cooled down before entering the convection part of the boiler, where the boiler tubes are positioned.

The first objective is achieved in the after-burning chamber. The second is met by designing the gas passages to allow sufficient time in the radiation zone of the boiler.

These objectives, we believe, are best achieved through a design incorporating a separate furnace and boiler. Compared with the integrated boiler design (water-wall furnace) the separate furnace and boiler design generally requires a marginally higher investment and, in addition, the heat recovery is, in theory, of marginally lower efficiency.

However, when operating costs are considered, the economics change dramatically. The ultimate decision is between marginal theoretical efficiency -- and reliability and availability.

Today, few, if any European incinerator designer/manufacturers still offer a pure water-wall furnace for incineration of urban refuse. Furthermore, specification for maximum steam outlet temperatures from incinerators are frequently being downgraded to 650-750° F following the many incidents of serious superheater corrosion experienced over the last 10 years or so.

Existing water-wall furnaces in operation in Europe have experienced severe erosion and corrosion problems in the water-wall sections. This has largely been a result of the previously mentioned fluctuation between oxidizing and reducing gas atmospheres in the furnace. Theoretically, the water-wall incinerator furnace can be operated with less excess air than the refractory wall incinerator because no air cooling is required for the furnace walls. It is this theoretical reduction in excess air that has produced the marginally higher fuel-to-energy efficiency.

However, the problem of corrosion of the water-walls has caused the plant operators and designers to increase substantially the amount of excess air, resulting in the elimination of this marginal boiler efficiency. Unfortunately, in most cases, increasing the excess air has not been sufficient to solve the corrosion problem.

Water-wall manufacturers, therefore, have now begun to install refractory linings inside the water walls in the furnaces. The immediate effect has been a reduction in furnace throughput capacity. For instance, the very large water-wall furnaces at the Ivry Incineration Plant in Paris have had their capacity ratings reduced from 50 to 40 metric tons per hour (1320 to 1056 short tons per day per unit) as a result of the relining required to deal with corrosion problems. In addition, fuel to energy efficiency has, of course, been reduced as well.

New so-called water-wall furnaces are, today, as a matter of course being designed with a refractory lining up to the end of the combustion zone. However, in a recent paper presented at the meeting of the Corner Tube Boiler Manufacturers' Association, a representative of one of the leading manufacturers of water-wall furnaces pointed to the still existing risk of corrosion in water-wall furnaces as a result of cracks in the refractory lining. It was pointed out that this corrosion would occur mainly in the areas where the refractory supports are welded to the water wall.

The same manufacturer according to a study completed for the U.S. Energy Research and Development Administration, (now Dept. of Energy) acknowledges the advantage of the refractory furnaces with respect to reliability. A previous incineration plant with refractory lined furnaces built by this company in Lausanne, Switzerland is now nearly 20 years old and is still available nearly 90 per cent of the time. The best that the same company has ever achieved with their early water-wall furnace designs has been about 75 per cent availability, and even today with their modernized water-wall designs the company will not guarantee more than 80 per cent availability.

Today, even where water-wall furnaces are installed in Europe most are refractory lined in the combustion zone. While the theoretically higher efficiency has been diminished by the design changes required by the problems discussed above, modified water-wall furnaces are still being specified by some consultants. It is understandable, given the time delay between European and American experience in incineration technology, that it will still be sometime before the North American market focuses on the greater reliability and actual fuel-to-energy efficiency of the refractory lined incinerator furnace.

Gunnar Kjaer

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Telephone 312-391-2341

August 30, 1979

Mr. David B. Sussman
Resource Recovery Division (AW-462)
U.S. Environmental Protection Agency
Washington, D.C. 20460

SUBJECT: Evaluation of European Refuse-Fired Energy Systems Design Practices. Review of Draft Report Volumes I to IV

Dear Mr. Sussman:

In accordance with your request, both UOP Inc. Solid Waste Systems and our technical collaborators, Josef Martin Company of Munich, West Germany, have reviewed the subject report prepared by Battelle Columbus Laboratories.

Josef Martin Company's review and comments were airmailed to you directly from Germany on August 22, 1979, with a copy to us. We have reviewed these comments and fully concur with Martin. In addition, we have also noted a few typographic errors, which we are sure will be corrected in editing. We have also observed that some tables have lost legibility in size reduction and printing, particularly Table A-15 on page A-40 and Table A-17 on page A-47.

On page A-54, paragraph two, the sentence after, "since all of ---" is not clear. The statement appears to imply "one of the units at most plants is down at all times." We suggest this sentence should be re-written to read, "For the purposes of scheduled maintenance, when one of the units is shutdown and remaining unit(s) cannot process all the refuse delivered at the plant, a pit capacity of 5-6 days storage is normally provided."

On page A-55, the first paragraph, second sentence states, "The most used shear is manufactured by Von Roll." This statement appears questionable. We assume the authors mean that all of the Von Roll plants visited had shears manufactured by Von Roll.

On Table A-21, page A-58, "Universal Oil Products" should read "UOP Inc."

On page A-59, second paragraph, "range in rates" should read "ratio of rates."

Mr. David B. Sussman,
U.S. EPA
August 30, 1979
Page Two

Page A-64, Table A-23, first line "room" should read "Ram."

Page A-71, Table A-24 - Overfire air per tonne for Paris Issy plant appears to be too high. Appears total combustion air (4235 M^3) is shown as overfire. Only 20-25% of combustion air is used as overfire.

We appreciate the opportunity of being allowed to review the subject draft report and hope you will find our comments useful.

We commend you and the authors of this most comprehensive report on European technology.

Very truly yours,

R.W. Seelinger

R. W. Seelinger
Engineering Manager
Solid Waste Systems

pt

c: Josef Martin Co.

JOSEF MARTIN FEUERUNGSBAU GMBH
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Mit Luftpost - By airmail

Mr. David B. Sussman
Resource Recovery Division
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U.S. Environmental Protection Agency
Washington, D.C. 20460
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Ihr Zeichen	Ihre Nachricht vom	Unser Zeichen	München Leopoldstr. 248
		Wd/AH	22 August, 1979

SUBJECT: Battelle Laboratories
Report: Evaluation of European Refuse-Fired Energy Systems Design Practices

Dear Mr. Sussman:

We refer to your recent agreement with Mr. Phil Beltz of Battelle covering possible corrections of the above-mentioned report. This report reached us only on 31 July 1979 so that the short period (deadline: 31 August 1979) indicated by you for submission of suggested corrections, allowed only a perusal for basic errors and misunderstandings and no thorough discussion.

We would praise the Battelle authors for their thorough and detailed summary and discussion of all technical information gathered on the occasion of their visits to the various European refuse incineration plants with generation of energy. It is understandable that in view of the great number of data confusions or mistakes crept into now and then, especially since there was the problem of the different languages, too.

.../2

Our perusal of the 4 volumes has mainly been concentrated on the passages referring to plants of the Martin system. Sometimes, we have also commented on general theories and philosophies of Battelle, however, would clearly state that we do not always share the authors' opinions.

We were somewhat disappointed at the fact to find again a great part of the errors and mistakes already contained in the preceding trip reports of Hamburg-Stellinger Moor, Paris-Issy-les-Moulineaux and Zurich-Hagenholz and meanwhile corrected with our letters dated 22, 23 and 26 February 1979.

Also the corrections submitted by TIRU in their letter to Battelle dt. 23 February 1979 have not been considered.

Due to the short period allowed to us we have no possibility of discussing this report with the plant managers of the 3 Martin plants mentioned. Therefore, we are not in a position to judge whether our clients agree to publications of data covering, for example, capital and operating costs or of way of financing. We hope that Battelle has obtained our clients' permission.

Furthermore, we have not corrected any misprints nor translation errors.

We are enclosing photostats of the pages where we have made corrections (marked in pink).

We kindly ask you or Battelle to modify the corresponding pages of the draft report to the effect of real information.

.../3

We would still briefly comment on a few pages, as follows:

Pages A-1, A-66, A-67, A-103, I-2, S-4, U-8

A great misunderstanding seems to have crept into here in so far as Mr. Tanner is called the originator of the modern-day water-tube wall refuse incinerator/boiler. Mr. Tanner may be called the originator of the waste heat boiler for refuse incineration plants, however, never the originator of the modern-day water-tube wall refuse incinerator/boiler. You may look this up in the two publications mentioned by Battelle on page A-67. Many years before Von Roll, Martin have equipped the furnace walls with boiler water tubes and this was severely criticized by Von Roll in competitions.

Page A-4

The quantity burned by the Hamburg-Stellinger Moor plant in 1976 was 200,556 mt refuse. The quantity of 420,680 mt indicated by Battelle refers to both Hamburg refuse incineration plants (Stellinger Moor and Borsigstrasse).

Pages A-61 and Q-8

1. On Hamburg-Stellinger Moor

Battelle has obviously misinterpreted an information obtained from Hamburg-Stellinger Moor. From the beginning of commissioning up to the year 1976, always individual grate bars only had been replaced, if required, during the annual maintenance periods of the stoker firing equipment in Hamburg-Stellinger Moor. From the year 1976 onwards, however, this maintenance schedule has been changed.

Since 1976, during the annual shut-downs for maintenance, it is no longer usual to replace individual grate bars, but to replace complete grate bar steps. Each step consists of 25 grate bars. The removed grate steps are refurnished in the plant's own workshop, individual grate bars are replaced, if required, and then the refurnished steps are held ready for the next maintenance shut-down. In the first year (1976) this procedure was applied, a great many bars, viz 24 % mentioned by Battelle, were replaced. In the second year, only 15 %, in the third year 1978 only 10.5 % were replaced, and it is expected that the replacement rate will go down to a figure from 5 to 10 % in the course of further operating years.

The above information was confirmed to us by the Hamburg-Stellinger Moor plant management on 22 August 1979 over the phone.

You will certainly agree with us that we demand that the figure of 24 % indicated by Battelle in the report, is changed to "less than 10 %", as it is completely wrong and may even do harm to our reputation, as compared to our competitors.

2. Zurich-Hagenholz

Also the figure of 7 % mentioned here is wrong. Upon inquiry, the plant management confirmed us on 22 August 1979 over the phone that within 40,000 operating hours only 32 grate bars were replaced, thus only approx. 0.8 %/year. The figure of 7 % indicated by Battelle is a composite value of all spare grate bars of the two older Von Roll units No. 1 and No. 2 and of the Martin unit No. 3. Here, too, we demand correction.

.../5

Page G-3

Contrary to Kaiser and Perry we have found out that in case of municipal refuse the difference between higher heating value HHV and lower heating value LHV is approx. 10 to 15 %:

For example:

for refuse at about HHV = 5000 Btu/lb the difference is approx. 11 %

for refuse at about HHV = 4000 Btu/lb the difference is approx. 15 %

Therefore, the formulas indicated by Battelle are very doubtful.

Pages R-10 and R-13

The photo R-7 shows a Martin ash discharger of the Bazenheid/Switzerland refuse incineration plant.

Here, too, we demand correction.

Page S-58

We think it necessary to clarify the term "Combustion Volume", otherwise the volume heat release ratesmentioned in table S-3 are not comparable.

Page U-27

The furnace roof tubes are part of the first stage superheater, are thus flown through by saturated steam or somewhat superheated steam. During start-up or shut-down of the boiler, radiation and too low a steam flow may cause local overheating of the tube wall, resulting in wall thickness reduction in the course of time. These tubes were never covered with SiC material.

Pages U-81 and U-83

The Yokohama-Totsuka plant has a completely different superheater design and should not be mentioned in this connection.

Page X-3

The regulation "TA-Luft" refers the indicated emissions to 11 % O_2, and not to 7 % CO_2.

We hope that you or Battelle will still make the corrections mentioned above and indicated on the enclosed photostats, if not, the value of the otherwise quite good Battelle report would be reduced considerably.

Very truly yours,
JOSEF MARTIN
Feuerungsbau G.m.b.H.

ppa.:

ENCLOSURES

Wheelabrator-Frye Inc.
ENERGY SYSTEMS DIVISION

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JOSEPH FERRANTE, JR.
Regional Vice President

September 12, 1979

Mr. Philip R. Beltz
Projects Manager
Energy and Environmental
Systems Assessment Section
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

Dear Phil:

You are in receipt of Von Roll's August 20th comments to your draft report, entitled "European Refuse-Fired Energy Systems - An Evaluation of Design Practices". The purpose of this letter is to relate some of our reactions to Volume I of this four-volume effort. I have also attached a copy of Von Roll's remarks which we received. I believe they are similar, if not identical, to the ones you already have.

In general, the report is excellent and makes a substantial contribution to the literature dealing with the subject. The following are some points to clarify to avoid misleading the uninformed reader.

- The inference is made that the approach to be used in Harrisburg is new. In reality, the use of steam to buildings' adsorption chillers is not new and has been widely practiced in major cities in the U.S. including New York and Boston. The second paragraph is therefore misleading. (Page A-33).
- Although "spending money for features to reduce corrosion and erosion generally increases investment" is true, it is a worthwhile investment to do so. The impact of the additional investment is minimal in comparison with the costs to maintain and replace boiler tubes without corrosion reduction features. (Page A-45, First Paragraph).

- It is not only the tax free bonding which favors private ownership in America; rather investment tax credits and accelerated depreciation are very important in making the private ownership decision. (Page A-46, Paragraph 2).

- It should be noted that in a third Munich unit, refuse is fired separately with coal. Munich has since concluded that coal and municipal solid waste should not be co-fired. (Page A-68).

- The second to the last paragraph should read "when Wheelabrator-Frye Inc. built the Boston North Shore plant in Saugus, Massachusetts, using the Von Roll design..." (Page A-72).

- The expression, "American thrust towards co-firing" is an overstatement. This should read, "... some of the American experimental efforts towards co-firing..." The inference that there is an American thurst in moving towards co-firing is not wholly justifiable. (Page A-92, Fourth Bullet).

- The dump fee costs indicated are misleading in that they suggest that they are real costs. In actuality, the disposal costs are much higher. (Page A-99, Second Bullet).

- It is misleading to suggest that the tipping floor method is an "American" system when in reality, the pit and crane method is more prevalent. The tipping floor method should not be given the characterization "American." (Page A-99, Next to Last Paragraph).

- The listing of U.S. installations is very misleading in that it includes:

    - Proposed projects which may never be built.

    - Projects which have been abandoned.

    - Non-municipal waste projects.

    - Non-energy recovery projects.

    - Experiments.

To include as comprehensive a list is not justifiable in a report on refuse-fired energy systems, since it leaves the impression that the U.S. has 89 implemented systems, when in reality there are less than 20 bona-fide refuse-to-energy projects in the U.S. Furthermore, the U.S. listing is not compatible with listings of other nations since it includes proposed projects. non-energy recovery projects, etc.

To leave the listing of U.S. systems in its present form would be a detriment to the report. (Pages B-57 - B-67).

- Why are Martin plants referenced as such in the report, while other manufacturers' plants are only referred to by the city in which they are located? The editors should be consistent. (Page I-29).

We trust that these comments can somehow be incorporated in your final report to EPA and appreciate the opportunity to have been involved in this project.

Sincerely,

Joseph Ferrante, Jr.

/pcl

cc: David Sussman

VON ROLL COMMENTS ON THE BATTELLE REPORT ON EUROPEAN REFUSE-FIRED ENERGY SYSTEMS

(Transcribed from Telex received 08/21/79)

As your just finished and very detailed report is mainly a tool for decision making for now and for the future, we think it is very essential, that as far as Von Roll's grate design is concerned, the report should concentrate on the design Von Roll is now applying and should report on the design given up by Von Roll in 1978 and inspected in the four rather old plants, only as far as it is necessary for a better understanding of our design applied now. We have discussed this problem with you and you have promised to consider a rewriting of the pages Q-9 to Q-14 due to the very short time, Von Roll had available for reviewing the entire report we are concentrating on the key items of our design, the grates and boiler. We ask you to use the following text for replacing the existing version in your report:

Von Roll Grate

1. Figures: Please change figures as follows:

Figure Q-2:	Two steps of Von Roll Grate using reciprocating forward-feed design. (Courtesy of Von Roll Ltd.) (Picture as shown in draft under Figure Q-3.)
Figure Q-3:	Improved Von Roll reciprocating step grate in refractory walled furnace. (Courtesy of Von Roll Ltd.) (Picture as shown in draft under Figure Q-2.)

2. Text for Pages Q-9 to Q-14:

Figure Q-2 shows in more detail the old standard Von Roll sloping reciprocating grate as it is used in most of Von Roll plants built before 1978. This original Von Roll grate, which is still in use in many of the larger Von Roll plants involves the alternating forward motion of adjacent grate "plates".

For smaller furnaces (that is 5 tons per hour or less) and particularly also for high calorific value trade waste Von Roll began 15 years ago install an improved grate composed of alternate fixed and moving rows in which each entire moving row of grate plates moves forward and backward together, thus eliminating the relative motion and grinding action between adjacent grate blocks. Von Roll is now applying this design to all new furnaces regardless of size. For existing plants, a grate system was developed by Von Roll, which can be mounted on top of the existing grate understructure and several plants have been modified in the meanwhile. Figure Q-3 shows a section of the modified grate at the Von Roll Gothenburg plant.

For new plants Von Roll developed the R-grate. A prototype of this grate is in operation since 1976 at the Von Roll Fribourg plant in Switzerland. The new system consists of a hydraulically driven feeding ram for volumetric charging and of a grate 6 to 12 meters long, 1.8 to 10.5 meters wide and with a declination of 18 degrees. The grate is built-up by 3 to 24 identical grate units linked together. For average and high heating values no grate steps are provided anymore, as this was done by Von Roll in its older design (see figure Q-2). For low heating values, however, grate drops still are provided also at the new R-grate to rearrange the heavy fuel bed as it tumbles down from an upper to a lower grate. Because of the "opening up" of unburned combustible surfaces as this tumbling action occurs, this point is in the furnace, one of the intense burning. To provide enough air at this point, in some plants, air is being admitted through the wall of the step to assure amply oxygen supply for the increased combustion rate.

The grate unit is the basic unit of the new R-grate system. Each unit consists of support structure, lateral sealing elements, four fixed transversal grate support, hoppers, zone separation walls and hydraulic drive units. The so-called drive carriage with the four mobile transversal grate support beams connected to the hydraulic drive is mounted on the support structure. The grate blocks are mounted on the fixed as well as on the mobile transversal grate support beams.

The drive carriage moving the four mobile rows of blocks is equipped with rollers running on inclined guiding tracks and supported by the two parallel longitudinal frame elements of the carriage. The guiding tracks are mounted on the longitudinal supports of the support frame.

The hollow grate block is equipped with cooling fins, enables forced cooling resulting in reduced wear and increased life span. The blowing of primary air through rectangular openings cast into the grate blocks results in high pressure loss enabling uniform distribution of the combustion air throughout the fuel bed independent from its thickness or distribution on the grate surface. Even substantial variations of the fuel bed do not change the uniformity of air distribution apart from negligible deviations. The chrome steel cast grate blocks are laterally machined. Each row of blocks is individually clamped together. Approx. 1,5 0/0 of the total grate surface of one section consists of air outlets.

The clamping device of the mobile block rows consists of two identical clamping brackets holding the clamping pins and the tie rods. The locking brackets are inserted in the first and last block of each row and frictionally connected by the tie rods located underneath the grate blocks. The fixed rows of grate blocks are locked in a similar way. This locking system reduces on one hand grate riddlings to a minimum, on the other the blocks remain firmly pressed together even in operating condition, preventing undesirable escape of air between them and securing continuous forced cooling.

The grate drive is hydraulic. Each grate unit is driven by two parallel cylinders mounted on the two lateral longitudinal supports of the support construction. The cylinder rods are connected to the drive carriage by shackle joints and move it for and back on the inclined guiding tracks. The grate blocks supported by the transversal beams move in the same rythm. The angular grate block form and the rapid stroke movement result in an excellent shifting and stoking effect. The fire spread evenly across the entire width of the grate at minimum dust development.

This grate drive system enables utilization of small and lightweight drive cylinders (approx. 16 kg/cylinder) for easy and quick exchange. Mounting or removal of a cylinder can be effected during operation owing to the newly developed drive and control system enabling control of each single drive unit separately. Therefore grates consisting of several grate units may operate at reduced load even during exchange of a cylinder.

The drive of the individual grate unit is not continuous as usual for today's systems but by electronic impulse control. Each grate sections is assigned the most suitable number of strokes depending on average waste heating value and progress of combustion. This number of impulses determines the respective waste travelling speed in the range of the respective grate unit. Based on combustion progress the optimum number of impulses is determined and adjusted for each grate section.

By this system the impulse number (number of strokes) of the whole grate can be uniformly increased or reduced for respective throughput alterations. The relation of the operating speed of the individual grate units, however, remains unchanged.

Owing to the application of electronic components it is possible at any time during operation to change the respective number of impulses of individual grate sections. Grates in boilers for heat recovery may for instance be controlled relative to the steam production by controlling the intervals between strokes.

Automatic firing control facilitates operation considerably since the operating staff has to control manually only in the case of a change of throughput.

Feeding Ram

Most important prerequisite of any automatic operation is uniform feeding. Von Roll applies a hydraulically driven feeding ram. It can be best compared with a drawer turned upside down. This drawer moves on a horizontal surface. The stroke speed is continuously variable by a remote oil flow control. The back stroke is effected at constant speed. Similar to the grate the ram is controlled with respect to steam production. Contrary to the grate, however, the stoke speed is continuously adjusted without any significant alteration of the waste quantity per stroke.

General Boiler Design

(Page U-8 to U-10)

Von Roll would like to comment, that the so-called tail-end boiler, consisting of a vertical waterwall combustion room and a horizontal convection section with hanging vertical tube bundles is a Von Roll development, applied first in the Lnadshut and in the Fuerth plant in Germany in 1971. A special feature of this boiler type is its inexpensive mechanical boiler cleaning by rapping of the bundles. This design is a very successful improvement towards high boiler availability. Since Landshut, Von Roll provided this boiler type for the plants in Mulhouse, France (1972), Quebec, Canada (1974), Angers, France (1974), Dijon, France (1974), Nyborg, Denmark (1975), Bezons, France (1975), Kempton, Germany (1975), Saugus, USA (1975), Emmenspitz, Switzerland (1976), Moncada, Spain (1975).

The only plant with some reservations about the quality of this boiler design is Saugus whereas the boiler unit number 1 at Landshut in the meanwhile is in operation fro approx. 51'000 hrs. without the need of a mechanical cleaning. We would like to draw your attention to that subject on a paper given at the CRE Conference in Montreux in 1975.

The adaption of this boiler type by W"E for Hamburg-Stapelfeld can simply be considered as a copy done by former Von Roll employees.

Finally, we would like to mention, that in the list of worldwide inventory of waste-to-energy systems we are missing some Von Roll plants. We are airmailing you today one newest reference list. Please note also, that the Volund Company did not participate at the delivery of the Nyborg Plant in Denmark.

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